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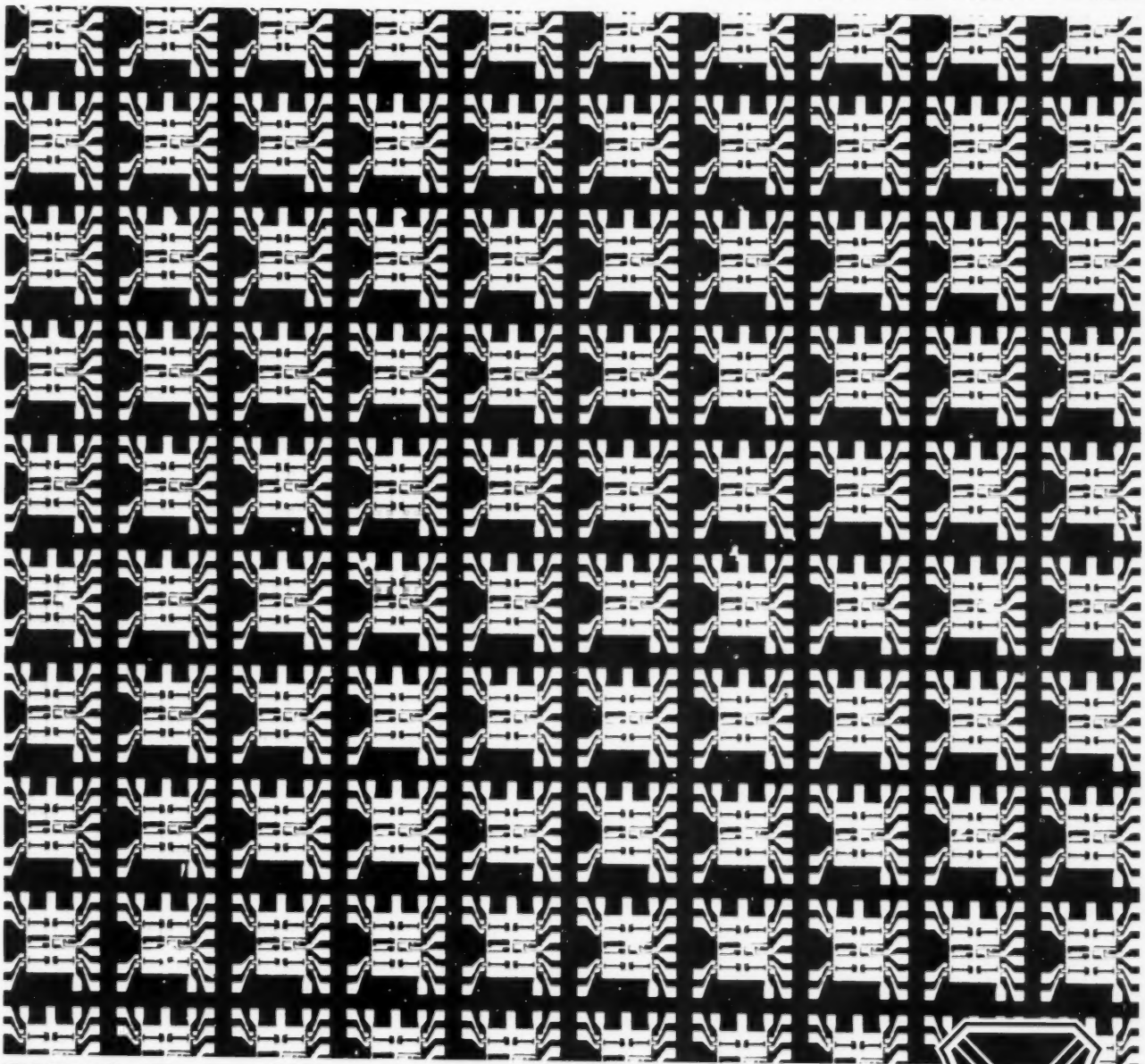

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OAR RESEARCH REVIEW

VOLUME VIII NUMBER 4 JULY–AUGUST 1969

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ON THE COVER:

The cover photo shows a 120-cell modifiable-logic array. Each cell has 10 transistors and 16 photoresistors. The photoresistors permit modification of the cell function, including the bypassing of injured cells, by means of light inputs. Future computers made up of similar arrays will be easily reparable and modifiable--both essential properties for unmanned space missions of long duration. Research in this area is being conducted by the Logic Technology Branch, Data Sciences Laboratory, AFCRL.

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JACOB SEIDEN *Editor*

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THE FUNDAMENTAL NUCLEAR INTERACTION, 1969

DR. ALEX E.S. GREEN*, University of Florida, Gainesville, Florida

1. INTRODUCTION

In 1960, Professor M. L. Goldberger remarked (1):

> There are few problems in modern theoretical physics which have attracted more attention than that of trying to determine the fundamental interaction between two nucleons. It is also true that scarcely ever has the world of physics owed so little to so many. In general, in surveying the field, one is oppressed by the unbelievable confusion and conflict that exists. It is hard to believe that many of the authors are talking about the same problem or, in fact, that they know what the problem is.

This bleak view at the beginning of this decade has changed dramatically as we near the close. (2) Indeed, we now have successful models which utilize the fields due to mesons, particles which have recently been produced with BeV (billion-electron-volt) particle accelerators. These theoretical models explain all the major features of the interactions between nucleons, i.e., neutrons and protons, as measured with nuclear accelerators whose energies range up to 400 MeV (million electron volts). This article will describe the nature of the fundamental nucleon-nucleon (N-N) interaction, as it appears from recent meson theoretic models.

2. CORRESPONDING FEATURES OF ELECTROMAGNETIC INTERACTIONS

It is helpful to illustrate the component nuclear interactions in terms of corresponding electromagnetic interactions which may be more familiar to the reader. For example, the repulsive electrostatic potential energy between two protons is $V_C = e^2/r$, where e is the charge of each proton and r is the radial distance separating them. This potential energy corresponds to the force $f = e^2/r^2$ (Coulomb's Law, 1785).

The coulomb potential energy is an example of a "central interaction" in that it depends only on the radial separation. When the interacting objects are dipole-like, e.g., two opposite charges separated by a distance, the interaction is more complex. It not only depends upon the radial separation (as r^{-3}) but also on the orientations of the two dipoles relative to the line joining them. Such a dipole-dipole type interaction also describes the interaction of two magnets (Gilbert 1595), and the interaction between two small current loops which behave like magnets.

The spin-orbit interaction occurs between a spinning charge, which acts as a little magnet or current loop, and a moving charge, which acts as a current element. This phenomenon corresponds to the well-known interaction of a compass needle or a magnetic dipole and a current (Oersted, 1820). Velocity dependent interactions between two moving charges correspond to the interaction between two current elements (Ampère, 1820).

Figure 1a illustrates the electromagnetic spin-orbit (Oersted) effect between two protons which are bound together by some nonelectrostatic force (let's say a rod with bearings at both ends). Figure 1b illustrates the "tensor" interaction between two parallel spinning protons (Gilbert). Borrowing upon the reader's experience with magnets, one can see that the system would seek to orient itself, as shown at right in Figure 1b. In other words, there will be a noncentral component of the force which would

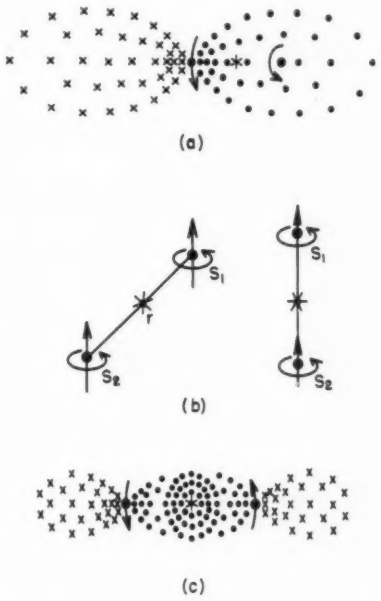

Figure 1.a. Diagram illustrating Faraday flux lines associated with moving and spinning positive particles leading to a spin-orbit interaction. Crosses represent flux lines into the paper; dots represent the flux lines coming up. The spinning charge on the right would seek to orient itself to line up with the flux lines set up by the moving particle to the left, e.g., the spin and orbital motions of like charges would tend to align in parallel.

Figure 1.b. Diagram illustrating the tensor force, a noncentral dipole-dipole type interaction between two spinning positive charges constrained to be parallel. The preferred orientation is to the right.

Figure 1.c. Diagram illustrating velocity-dependent forces, or p^2 forces (Ampère). The compression of flux lines between the two particles would tend to push the two protons apart.

**Dr. Green's research has received support since 1965 from the Nuclear Physics Division, Directorate of Physical Sciences, AFOSR (OAR).*

act to push the system into alignment. Figure 1c illustrates the velocity-dependent interaction between two protons by virtue of their motion around each other.

These three magnetic interactions are dynamic or relativistic interactions arising from the motion or spin of charged particles. According to modern quantum field theory, these interactions arise because protons exchange photons which are the particles of the electromagnetic field. Though photons have no mass, they do convey energy and momentum. Because they have one unit of angular momentum, they are known as vector particles.

3. NUCLEAR INTERACTIONS

By 1932 nuclear experiments had revealed that nuclear forces act only over very short ranges ~2F where F, a Fermi, is equal to 10^{-13} centimeters. This short radius of action was explained by Yukawa in 1935 as a consequence of the fact that the quanta (mesons) which convey the nuclear force have a finite mass in contrast to the "massless quanta" (photons) of the electromagnetic field. Because of this feature, the e^2/r potential of electromagnetic theory is replaced in the corresponding vector form of meson theory by a potential energy $V_V = g^2 Y$. (See the equation for Y in Fig. 2.) Here m is the mass of meson field and g is a coupling constant analogous to electric charge e. Note that when $m \to 0$, $\mu \to 0$ and, since $e^{-0} = 1$, $Y \to 1/r$. Thus, the Yukawa function contains the 1/r function of the electrostatic potential as a special case when the mass of the field quanta vanishes. The function Y(r) is identical in mathematical form to the Debye potential used in studies of electrolytes and plasmas.

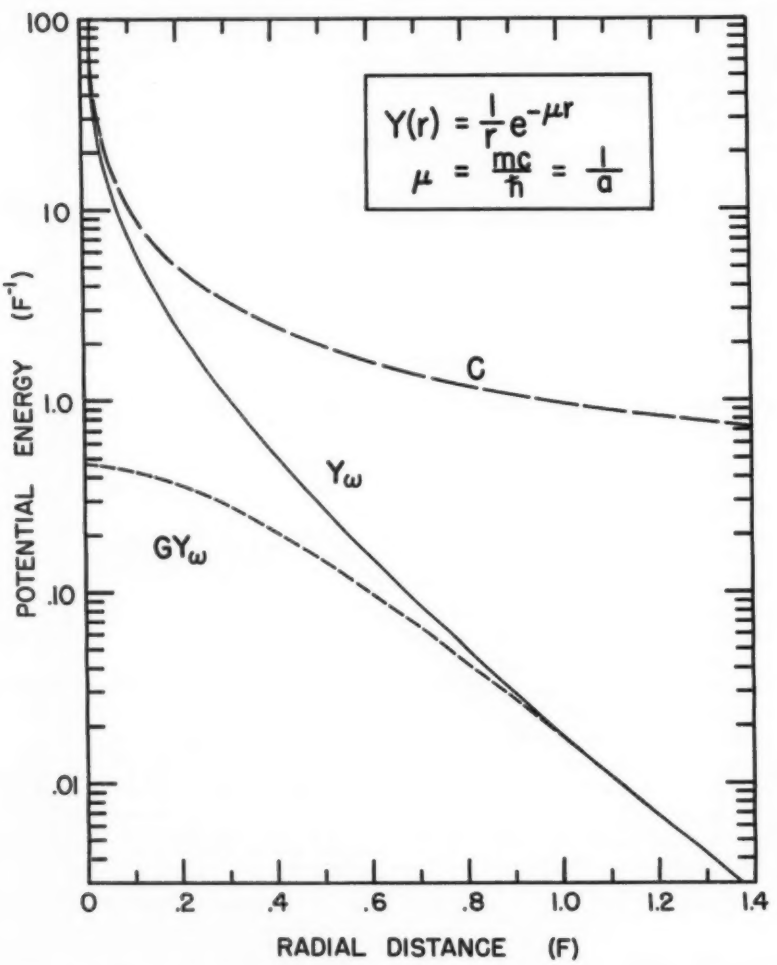

Figure 2. Static potentials. The equation for the Yukawa function, the decay constant μ, and the range a are given in the box. C denotes the Coulomb function, and Y_ω denotes the Yukawa function for the ω meson mass. GY_ω is a generalized Yukawa function associated with the ω meson. A logarithmic vertical scale is used to encompass the large range of values. Note that $Y \to C$ as $r \to 0$, and also that $GY_\omega \to Y_\omega$ as $r \to \infty$.

The curve C in Figure 2 represents the Coulomb function $C = 1/r$ which might also be viewed as a Yukawa function corresponding to zero meson mass which has an infinite radius of action. The curve Y_ω in Figure 2 corresponds to the Yukawa function for the ω meson, a spin-1 particle whose mass (782 MeV) gives the radius of action a = 0.25F. The curve $GY\omega$ is a weighted combination of Yukawa's, whose weights are prescribed by a generalized form of meson field theory (see below). According to this theory, the generalized Yukawa function is finite at r = o in contrast to the ordinary Yukawa function, which goes to infinity (as r^{-1}).

The vector form of meson theory based upon spin-one particles was proposed by A. Proca in 1936. Yukawa himself originally proposed a scalar field theory based upon mesons having zero spin. Such a theory leads to an attractive interaction $V_S = -g^2 Y$. (This interaction is somewhat analogous to the attractive gravitational interaction between protons, in contrast to the repulsive electrostatic interaction.)

Suppose, instead of a scalar field alone, one has a synthesis of a scalar field and a vector field with about the same masses and coupling constants. In this combination, the attractive static term arising out of the scalar field is cancelled by the repulsive static term associated with the vector field. The residual forces are then very complex, since they are entirely relativistic, of the nature of magnetic forces alone. Furthermore, if the coupling strength g^2 is large, then the residual relativistic interactions could be sufficiently large to explain the nature and magnitude of the nuclear interaction.

A combination of vector and scalar meson fields with identical masses and coupling constants, together with generalized Yukawa functions, was studied by the writer some 20 years ago. (3) The combination leads immediately to cancellation of the major static scalar and vector interactions. The generalized feature of the field theory suppresses all the infinities which plague ordinary meson field theory. In the theory, a residual attractive central interaction arises from the scalar meson which, if g^2 is large enough ($\sim 2000e^2$), would be sufficient to hold nuclear particles together. In addition, spin-orbit, tensor, and velocity-dependent interactions analogous to the magnetic interactions illustrated in Figure 1 survive among the residual terms.

The pseudoscalar field, first introduced by N. Kemmer in 1938, was also included in the theory. Such a field, exemplified today by the π meson and the η meson, gives rise only to relativistic interactions: a spin-spin and tensor force.

The π meson discovered experimentally in 1947 is particularly interesting since, because of its light mass, it has a long range of action (a_π = 1.41F). Hence, the π meson field dominates the N-N interaction at large distances ($r > 2F$). The π meson and ρ meson, unlike the ω meson, which is neutral, come in positive, negative and neutral charges. (Note that, for such particles, the effective interaction can be repulsive or attractive, depending upon the state of the two nucleons.) This variability complicates their action somewhat; for such particles, the effective interaction can be either repulsive or attractive, depending upon the angular momentum state.

Meson theory of nuclear forces in the 1950s was primarily pursued in terms of the π meson field. While this field was quickly able to explain the outer region of the nucleon interaction, i.e., $> 2F$, our understanding of the middle region (between 1 and 2F) evolved very slowly. Progress in large measure was the result of tedious phenomenological analyses of experimental data by a number of scientists, particularly by Gregrory Breit and Malcolm MacGregor and their collaborators. By the beginning of the present decade, a fairly consistent phenomenological representation of the experimental data became available for the testing of theoretical models.

4. THE N-N INTERACTION, 1969

The discovery of the vector mesons ω and ρ in 1961 stimulated attempts to build up an N-N interaction out of a mixture of these vector mesons along with the π meson. In a π-ω mixture, however, the large, repulsive static term of the ω vector meson so dominates the interaction that little sense could be made with the theory until the scalar meson, then undiscovered, was included. Its *ad-hoc* purpose was to cancel or approximately cancel the repulsion, yet preserve the spin-orbit term which was needed to explain certain experimental observations related to the spin orientation of scattered particles.

This approach was adopted almost simultaneously by several groups in Japan and America, using several different mathematical formalisms. By 1964 successful meson theoretic models of the outer and middle regions of the nuclear interaction were developed by the Japanese group of S. Sawada, T. Ueda, W. Watari, and M. Yonezawa, and the California groups of J. Ball, A. Scotti, and D. Y. Wong, and R. L. Bryan and B. L. Scott. The models became known as one-boson exchange models, since mesons are bosons, and only single-particle exchanges are usually included. The close similarity of the potentials in the last study with those obtained in his work between 1947-1949 led this author to resume his studies of relativistic models with generalized Yukawa functions. Then,

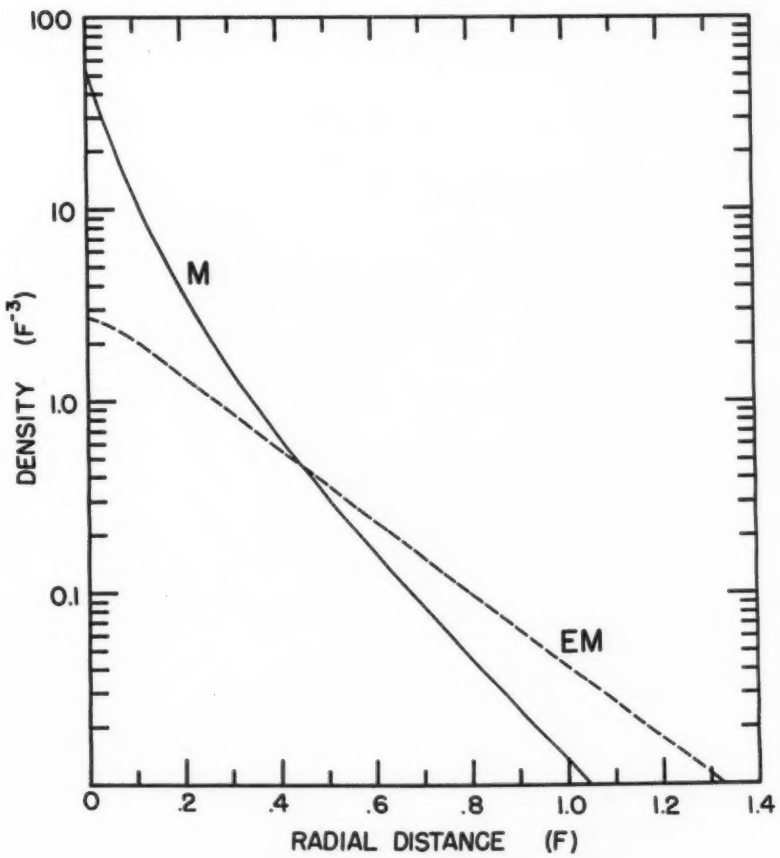

Figure 3. The EM curve represents a static-charge density which can be associated with recent measurements at the Stanford Linear Accelerator Center. The M curve gives the mesonic density on the Green-Ueda peel-off model.

in a series of studies in collaboration with R. Sharma, T. Sawada, G. Darewych, T. Ueda, A. Gersten, A. Dainis and others, a number of models were found which not only provided a good description of a middle range of the nuclear force, but also of the very inner range (<1F). (4) The key elements in the Florida work which accounted for their success in the inner region was their inclusion of the velocity-dependent (Ampère) terms in the N-N interaction and the use of generalized meson fields.

Recently, T. Ueda and this author have given a detailed reinterpretation of a generalized Yukawa potential in a context of nucleons surrounded by their meson clouds. Such features of nucleons were first observed experimentally by Hofstadter and his collaborators in 1955 using 500 MeV electrons. A very precise fit to the most recent measurements made at the Stanford Linear Accelerator Center with 20 BeV electrons has been obtained by Green and Ueda (5) using equations arising out of generalized meson field theory. Figure 3 illustrates radial density functions corresponding to the Green-Ueda expressions. In the original nongeneralized forms of field theory, these densities were infinite and had zero radial extensions, features which caused great difficulties.

Figure 4 illustrates experimental angular distributions (differential cross sections) obtained in neutron-proton scattering experiments, along with the results of a theoretical model (Ueda-Green-III). (4) The model also provides a rather good account of the properties of the deuteron (a bound neutron-proton system) along with all the other scattering data, including total cross sections, polarizations, depolarizations, and other observable parameters too complex to describe here.

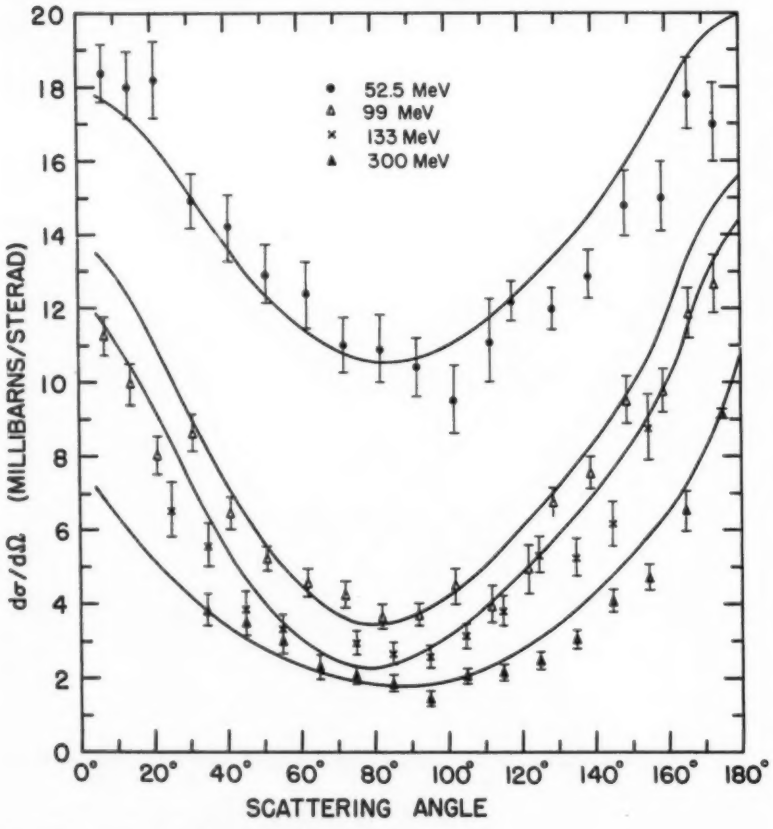

Figure 4. Angular distributions of neutrons scattered by protons as represented by differential cross sections. The experimental data are shown by points along with error limits. The curves are for the Ueda-Green-III model which illustrates fits with generalized one-boson exchange potentials.

The model uses fields associated with the well-known π, η, ω, and ρ mesons and s_0 and s_1 scalar mesons with the same masses as their vector meson counterparts (the ω and ρ). A scalar meson like the s_0 has recently been observed experimentally. The model contains one hypothetical component, a weakly coupled light scalar meson which is introduced phenomenologically to represent miscellaneous minor effects. According to this model, the N-N interaction consists primarily of residual static and dynamic interactions arising from the exchange of vector, scalar, and pseudoscalar mesons. The dynamic terms are direct analogues of magnetic interactions illustrated in Figure 1. In this theory, nucleons are distributed sources rather than points, and hence give rise to generalized Yukawa functions which are finite everywhere.

The Ueda-Green-III model achieves good fits to experimental data with about one tenth the number of adjustable constants used in phenomenological models not based upon meson field theory.

Much remains to be done to improve the precision of the fits to the data and to reduce further the number of adjustable constants. Furthermore, the OBEP (one boson exchange potential) model of the N-N interaction has yet to be related in detail to other studies in nuclear and particle physics. Nevertheless, it is gratifying that a reasonably simple and accurate description and an appealing physical picture of the fundamental nuclear interaction has finally emerged. It would appear that the time is approaching when nuclear physics will become, like atomic physics, a science based upon known physical laws.

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(4) Ueda, T. and A. E. S. Green, *Phys. Rev., 174,* 1304, 1968.
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Dr. Alex E.S. Green (with glasses, bending over desk) is shown with Professor Tamatsu Ueda of Osaka University (standing at left) and Larry Simmons of the University of Florida (sitting). Dr. Green is a Graduate Research Professor of Physics and Astronomy at the University of Florida. He has also taught at the University of Cincinnati, where he received his Ph.D., and at Florida State University, and has done research at the Oak Ridge National Laboratory, Los Alamos Scientific Laboratory, and General Dynamics Astronautics and Convair Divisions.

Dr. Green also serves as a consultant to the Jet Propulsion Laboratory, the Institute for Defense Analyses, and the Marshall Space Flight Center. In addition to being the author of a number of works, including *Atomic and Space Physics*, *The Nuclear Independent Particle Model*, and the classic *Nuclear Physics*, he is a Fellow of the American Physics Society and past Chairman of the Space and Atmospheric Physics Committee of the American Institute of Aeronautics and Astronautics. He received the Medal of Freedom for his World-War-II services as an operations analyst with the Twentieth Air Force.

In addition to his interest in the nucleon-nucleon interaction, Dr. Green also works in theoretical atmospheric, space, and nuclear physics.

a new trapping technique for free radicals

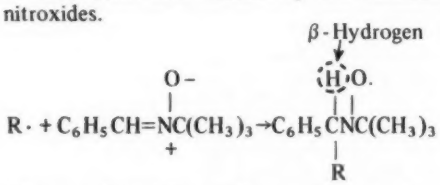
DR. ANTHONY J. MATUSZKO,
Directorate of Chemical Sciences, AFOSR

When a chemical bond is broken, one result might be the formation of reactive fragments with one or more unpaired electrons. Such reactive species are called "free radicals." To illustrate, the homolytic cleavage of a carbon-hydrogen bond in methane would yield a methyl radical, in addition to a hydrogen atom:

methyl radical

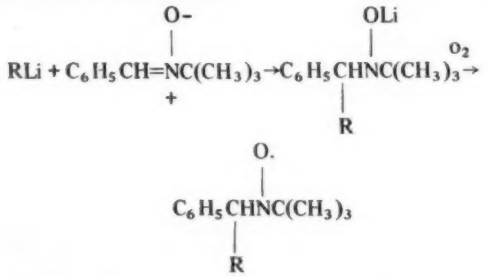
Free radicals such as these may be the needed reactive intermediates in the synthesis of new materials, or they may be the breakdown products in the high-energy radiative degradation of a structural material. In general, free radicals are very short-lived species ($\sim 10^{-3}$ to 10^{-8} sec) and exist at low concentrations. An extremely useful tool for the study of chemical species with unpaired electrons is electron-spin-resonance (ESR) spectroscopy. It can yield information not only of the presence and number of such unpaired electrons, but also of the distribution of the electrons in the molecule.

Relatively high concentrations (above 10^{-8} M) of free radicals are usually required for ESR studies at room temperature with commonly available equipment. Numerous methods have been developed for studying short-lived free radicals by *in situ* irradiation or rapid mixing techniques. Biochemists have used a technique wherein the sample is frozen immediately after rapid mixing and studied at the experimenter's leisure. However, the ESR signals, which are frequently broad and relatively featureless, cannot give the required information for structural determination. A need has existed for readily applicable methods for detecting and identifying low concentrations of free radicals (below the ESR detection threshold) in reacting systems. With grant support from the AFOSR Directorate of Chemical Sciences, Dr. Edward Janzen of the University of Georgia has developed a trapping technique for this purpose. The approach is to have the generated radical react with a compound that can serve as an efficient radical trap. (We call these compounds *spin traps*.) Thus, a radical, at low concentration and formed relatively slowly, could be trapped to produce a new and more stable radical easily detectable by ESR. (We call these new radicals *spin adducts*.) The nature of the resulting ESR spectrum could then tell us the structure of the original radical. Of course, the spin adduct formed by this trapping technique must be reasonably stable and detectable by ESR. If the hyperfine spectrum of the resulting spin adduct has a characteristic feature which is sensitive to the detailed structure of the attached groups, the information can be used to identify the original radical. One such spin trap which Dr. Janzen and his research group have generated is phenyl t-butyl nitrone (PBN), which has been used for the identification of short-lived free radicals by the formation of stable nitroxides.



Whereas the original radical would have been difficult to detect, the ESR spectrum of the nitroxide radical provides information not only about the existence of free radicals in the system, but also on the structure of the radicals. (The structural information is obtained from the magnitude of the hyperfine splitting of the β-hydrogen as observed in the ESR spectrum.)

To be an effective spin trap system, the reactions which give phenyl radicals should give the same spin adducts with the same characteristic features in the ESR curve. In addition to phenyl radicals, the approach has been used successfully to define the structure of the radicals trapped in the benzyl, methyl, trifluoromethyl, ethyl, n-butyl, acetoxy, and benzoyloxy radicals. The structure of a few spin adducts was verified by the synthesis of the appropriate secondary amine, followed by oxidation to the nitroxide. Further verification was obtained by the addition of organolithium compounds to PBN, followed by air oxidation to the nitroxide.



The accompanying table summarizes the source of a number of radicals and the type of radical trapped. A communication in the *Journal of the American Chemical Society* (1) further describes methods used for generating the various free radicals, and gives the calculated coupling constants of the nitroxide radicals formed. Because of this paper, and his presentation on the subject at the National Meeting of the American Chemical Society in September 1968, Dr. Janzen has been contacted by other researchers from various parts of the world. Letters from two research groups (one from Strasbourg, France) ask essentially what this new trapping technique can do to answer the question: "Are there free-radical intermediates in the reaction I am studying?"

Table I
Free Radicals Studied
by the Trapping Technique

Radical source	Radical trapped
Phenylazotriphenylmethane	C_6H_5
Dibenzylmercury	$C_6H_5CH_2\cdot$
Trifluoromethyl iodide	$CF_3\cdot$
Dimethylmercury	$CH_3\cdot$
Diethylmercury	$C_2H_5\cdot$
Di-*n*-butyllead diacetate	$C_4H_9\cdot$
Lead tetraacetate	$CH_3COO\cdot$
Benzoyl peroxide	$C_6H_5COO\cdot$

This new method of detecting short-lived free radicals in low concentrations will be useful to the Air Force not only in the synthesis of new materials through free-radical intermediates, but also as a sensitive technique for detecting the degradation of polymeric materials upon exposure to the high-energy radiation of the upper atmosphere. Other general applications are spin trapping in biochemical systems, polymerizations, and air-pollution studies.

REFERENCE

(1) Janzen, Edward G. and Barry J. Blackburn, "Detection and Identification of Short-Lived Free Radicals by an Electron-Spin-Resonance Trapping Technique," *J. Am. Chem. Soc., 90,* 5909, 1968.

CORONAL ARCHES

SACRAMENTO PEAK OBSERVATORY, AFCRL

We have all seen photographs of the brilliant solar corona--the bright halo of light surrounding the dark disk of the sun during eclipses. Its ragged edges and streamers can be seen to jut out some 4 million km from the central disk. When these eclipse photos are examined carefully, structural features can be seen. The most puzzling of these features are arrays of concentric arches, with the outermost arch of the multiple-arch structure extending out in a giant looping swath about 300,000 km from the solar limb. (These neatly organized arches should not be confused with the more familiar and spectacular solar loop prominences.)

Multiple-arch systems were first observed in coronal photographs taken during the eclipse of June 29, 1927, in North Sweden, and have since been seen many times. Typically, the arches consist of three or four equidistant concentric components, elliptical in shape. The feet of the arches extend down to the lowest solar atmospheric element, the chromosphere. At the center of the multiple-arch system is a solar prominence.

What is the origin of these symmetrical forms? Are we observing true arches, or some structure that gives the illusion of concentric arches? What is the source of energy for the relatively bright structures? In his paper, "A Concentric-Ellipse Multiple-Arch System in the Solar Corona," published recently in *Solar Physics*, Dr. Charles L. Hyder of AFCRL's Sacramento Peak Observatory at Sunspot, N.M., and Dr. Kuniji Saito of the Tokyo Astronomical Observatory (associated part time with the AFCRL Observatory) examine these questions, and review several theories on the formation of the observed coronal structures. They then present a model which they believe realistically accounts for the arch system. In their paper, they focus attention on a photograph, taken during the February 4, 1962 eclipse in New Guinea, which shows 4 egg-shaped arches with greater diameters in the vertical than in the horizontal direction--roughly 300,000 by 200,000 km for the outermost arch. The average distance from the foot of 1 arch to that of its nearest neighbor is about 24,500 km.

However, what appear to be arches on the photographs could actually represent quite a different structure, an illusion created by limited visual clues. For example, we may be observing several dome structures, with progressively smaller domes fitting cup-like inside larger ones. The thicker, and therefore brighter, cross sections of the sides of the domes would appear to be arches on photographic plates. Another configuration that would give the appearance of arches would be several horizontal bright and dark bands, with the width of each band increasing with altitude. Viewing such bands along their axis--end on--would give the appearance of multiple concentric arches. The AFCRL authors conclude, after analyzing these possibilities, that the observed structures are in fact arches.

They suggest that the arches are rod-like in form and are visible manifestations of magnetic rods located symmetrically on opposite sides of the central solar prominence. Their brightness is sustained by a flow of electrons from clusters of spicules (bright filaments in the solar chromosphere having a grass-like structure) at the base of the arches, electrons which are confined by the arching magnetic field. In addition to their calculations showing how the influx and efflux of electrons into and out of the magnetic rods maintain equilibrium, they speculate that the diameter of the arch rod is roughly determined by the size of spicule clusters (rosettes), and that the separation between the arches (24,500 km) is somehow related to supergranules--giant upswellings of convective currents from the solar interior, a single cell of which may extend across 30,000 km.

CLASSIFICATION OF SOLAR-PROTON EVENTS

SPACE PHYSICS
LABORATORY, AFCRL

Almost every solar "hiccup" is presently being reported as a solar-proton event. The lack of a standard reporting system, according to two AFCRL astrophysicists, D. F. Smart and M. A. Shea, is confusing to those who try to understand solar-proton events and cope with their effects. At the first general meeting of the Inter-Union Commission on Solar Terrestrial Physics held in London from January 26-31, 1969, they proposed a method of classifying solar-proton events by intensity. Because of its favorable acceptance, this classification system will probably see increasing use by the growing international fraternity of astrophysicists who study solar-proton events and their consequences.

A general impression exists that solar-proton events are bad. However, solar-proton events may be large or small, with a continuum of sizes in between. A small event has little or no effect on space operations or on the earth's environment. A large event, on the other hand, presents an ionizing hazard to men in space and to electronic equipment aboard space vehicles. It can induce serious degradation in the performance of ground-based electronic systems used for Arctic communications, navigation, and radar surveillance, causing polar-cap absorption--or radio blackout.

The origin of high-energy solar protons is not completely understood. All proton events are associated with solar flares, but not all solar flares produce a proton event. One commonly accepted theory on the origin of these energetic protons is that they are accelerated by magnetic fields associated with sunspots. (See Figures 1 and 2)

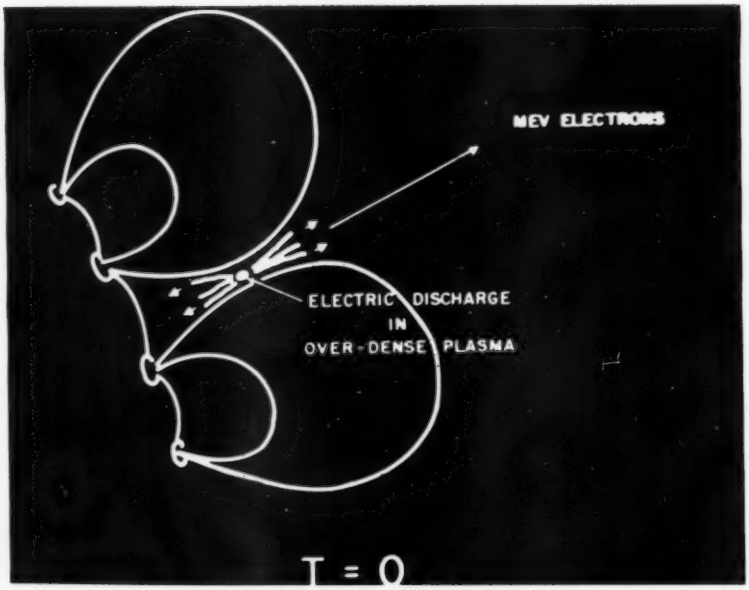


Figure 1. Initial Condition (T=0).

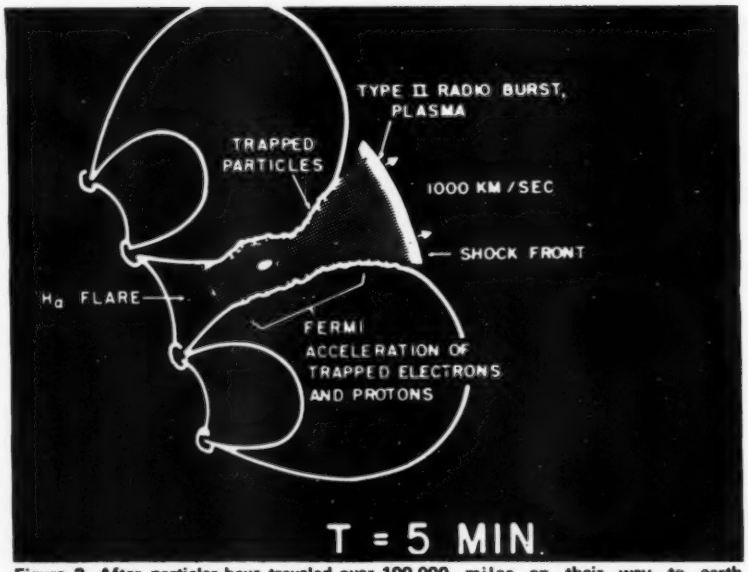


Figure 2. After particles have traveled over 100,000 miles on their way to earth (T = 5 min.).

These two illustrations demonstrate one theory on how high-energy protons are generated. Essentially, two magnetic fields are present. Ionized particles--that is, high-energy protons--erupting from the sun are channeled in the space between the two magnetic fields and accelerated. This initial condition is shown in Figure 1, where T = 0. After five minutes (T = 5 min.), the accelerated particles have traveled more than 100,000 miles on their way to earth. (See Figure 2)

Solar protons can be measured directly only by sensors above the earth's atmosphere; but these sensors have not always been aloft to provide continuous monitoring. Over the past 10 years large numbers of direct satellite measurements have been made, and these measurements have been correlated with effects measured by ground-based neutron monitors and

riometers. Thus, the data from these ground-based instruments can be roughly translated into intensities of proton events.

The intensity of a solar-proton event is characterized by two interrelated parameters--the flux (or the number of particles that pass through a square-centimeter aperture in space each second), and the energy of the particles. The Smart-Shea classification system is based upon a flux of particles at some specified energy level. They have suggested that a reference energy of 20 MeV be used, although this choice is admittedly arbitrary.

A second feature of the classification system is the threshold value — that is, the intensity level at which their scale of increasing intensities begins. In the Smart-Shea scheme, it starts with the normal cosmic-ray background, which remains relatively stable. (There is no way for an instrument to distinguish between a charged particle that originates in the sun and one that originates in space.)

The classification system has 5 levels of intensity ranging from 0 through 4, with 4 being the most intense. This system is patterned after the one presently used to classify the importance of solar flares. Beginning with the cosmic-ray background threshold, each intensity level is separated from the preceding level by 2 orders of magnitude in terms of particle flux. For example, a proton event classified as an importance -1 event would have a particle flux exceeding the threshold of 0.3 particles (20 MeV or greater) per square centimeter per second, while a flux exceeding 30 such particles would be rated as an importance -2 event. The 5 levels of intensities are arranged by Smart and Shea into a matrix permitting the translation of riometer observations (expressed as db of absorption) and neutron monitors (expressed as percentage increase over normal) into terms of particle flux for each level of intensity.

Although the classification system will require refinement if placed in general use, it provides, even in its present state, the best objective method available for describing the intensity of solar-proton events in quantitative terms.

Peggy Shea (left) and Don Smart have published widely—some of their papers becoming landmark papers—in the field of charged particles in space. Their proton-classification system was recently adopted by an international body of solar astrophysicists.

Mr. Don F. Smart is a physicist at the Cosmic Radiation Branch of AFCRL's Space Physics Laboratory, and is also currently Acting Chief of the Branch. He has been working on the problems of the "optics" of cosmic radiation, including the asymptotic direction of approach allowed through the earth's magnetic field and cosmic-ray cutoff rigidities. He is also engaged in designing and coordinating cosmic-radiation experiments for Air Force rocket and satellite systems, and is concerned with data analyses, contract monitoring, and data-processing problems arising in the use of satellite vehicles for conducting geophysical research.

Mr. Smart attended the Utah State University from which he received a Bachelor of Science in Physics in 1957. After graduation from college, he worked for the U.S. Naval Ordnance Laboratory of Corona, California on guided-missile fusing until ordered to active duty as a lieutenant in the Air Force. He was assigned to the Geophysics Research Directorate of the Air Force Cambridge Research Center (predecessor of AFCRL), where he worked as a physicist specializing in rocket and satellite instrumentation. After completing his active duty in February 1960, he remained with the Geophysics Research Directorate as a civilian physicist.

Mr. Smart is a member of the American Geophysical Union and the American Association for the Advancement of Science. He has received the Special Act of Service Award for his work on the STARAD satellite.

Miss Peggy Ann Shea is a research physicist (nuclear physics) at the Cosmic Radiation Branch of AFCRL's Space Physics Laboratory. Currently, she is conducting research involving the behavior of solar-flare particle radiation, primary cosmic radiation, and intensity-time variations. She is also developing methods of utilizing digital computers for cosmic-ray data processing and analysis.

Miss Shea attended the University of New Hampshire, Durham, N.H. and, in 1958, received a B.S. degree in Physics from the College of Engineering. In 1961 she received an M.S. degree in Physics from the same university. Before coming to AFCRL, she had worked in cosmic-ray physics at the University of New Hampshire, and as a physicist at the University of Hawaii. She had also been employed as an associate scientist in the Geophysics Section of the AVCO Corporation, Wilmington, Mass.

Miss Shea received the Sustained Superior Award in May 1966. She is a member of the American Geophysical Union, the American Physical Society, and Sigma XI.

cognition, crossroads for artificial intelligence and anthropology

ROWENA SWANSON, Directorate of Information Sciences, AFOSR

The field of artificial intelligence is one of the principal exemplars of today's trend in multidisciplinary intellectual and research activity. It is increasingly being enriched by contributions from mathematicians, engineers, psychologists, neurophysiologists, and linguists. Recently, a rapprochement was explored with anthropology.

During the first week of March 1969, a group of researchers from the artificial-intelligence and anthropology communities met in Chicago under the auspices of the Wenner Gren Foundation for Anthropological Research, Inc., to consider the topic, "Cognitive Studies and Artificial Intelligence." (1) Their mission was to examine current knowledge from both groups on human cognitive processes that each, in turn, could apply in its own pursuit.

Dr. Humberto R. Maturana, professor of biology at the University of Chile in Santiago and visiting researcher at the University of Illinois Biological Computer Laboratory, (2) set the tone for discussion at this Symposium. His insightful comments on the nature of cognition are based on his work in neurophysiology and his long association with artificial intelligence. (3) Starting from the proposition that "cognition is a biological phenomenon," he elaborated as follows:

A. With respect to the observer:

> "Anything said is said by an observer. We as observers behold simultaneously the organism and its environment. This allows us to interact independently with both and to have interactions that are necessarily outside the domain of interactions of the observed entity (the organism). It is an attribute of the observer to be able to interact independently with the observed entity and with its relations; for him both are units of relations (entities). For the observer an entity is an entity (a unit of relations) when it can be described. .... The observer can describe an entity only if there is at least another entity from which it can be distinguished and with which it can interact, even if this is the observer himself, and which serves as a reference for the description. .... Any understanding of the cognitive process must account for the observer and his role in it."

B. With respect to living systems:

> "Living systems are units of relations; they exist in an environment. From a purely biological point of view they cannot be understood independently of the part of the environment with which they interact, the niche; nor can the niche be defined independently of the living system that occupies it. Living systems as they exist on the earth today are characterized by exergonic metabolism, growth, and replication (and reproduction), all organized in a closed causal circular process that allows for evolutionary changes in the way the circularity is maintained, but not for loss of the circularity. .... It is the circularity of its organization that makes a living system a unit of relations, and it is this circularity that it has to maintain to remain a living system and retain its identity through different interactions. .... The circular nature of their organization makes living systems self-referring systems: their condition of unit of relations is maintained because their organization has functional significance only in relation to its maintenance and defines its domain of interactions accordingly. Living systems as relational units cannot enter into relations that are not prescribed by their organization. .... The predictions implied in the organization of the living system are predictions of classes of interactions (relations), not of particular events. This makes them inferential systems, and their domain of relations a cognitive domain. .... For every living system its niche is represented in its organization as the domain of its possible interactions (relations) and this domain constitutes its entire cognitive reality."

C. With respect to evolution:

> "Evolutionary change in living systems is a result of their organization which secures the maintenance of a circular process allowing, in each reproductive step, for changes in the way it is attained. Reproduction and evolution are not essential for the living organization, but they have been essential for the evolution in the cognitive domains of the living systems on earth. .... What changes from generation to generation is the unit of relations: that which, through a self-referring circular organization, retains its identity through numerous interactions."

D. With respect to cognitive processes:

> "A cognitive system is a system that defines a domain of relations in which it can act with relevance to the maintenance of the system itself, and the process of cognition is the actual (inductive) acting (or behaving) in this domain. Living systems are cognitive systems, and living, as a process, is a process of cognition. This statement is valid for all organisms, with and without a nervous system. .... The nervous system enlarges the domain of possible interactions of the organism and is instrumental in making

the internal states of the living systems also modifiable in a relevant manner by 'pure relations,' and not only by physical events. . . . . The nervous system . . . . does not create cognition. . . . . As a result of the expansion of this domain there are organisms that include as a subset of their possible interactions, interactions with their own interactions, generating the paradox of including their cognitive domain in their cognitive domain. In us this paradox is resolved by what we call consciousness (a new cognitive domain); we are cognizant of our own cognitive process: we enter into relations with our cognitive process.

"The expansion of the cognitive processes (acting and interacting) in the domain of pure relations by the nervous system has made possible nonphysical interactions between the organisms, and hence communication. But this has generated a second paradox: there are organisms that generate representations of their interactions, by defining entities and their descriptions, with which they interact as if they belonged to an independent domain, while as representations they only map their interactions. In us this paradox is resolved by our becoming observers: we recursively generate representation (and their descriptions) of our interactions, and by interacting with them and their interactions remain in a relational domain always larger than that of the representation."

How do we "see" when we see and, more explicitly, how do we accomplish the feat of "knowing?"

"For the animal to see an object the eyes have to absorb the light quanta; yet the object that the animal sees is defined by the relations that the anatomical and functional organization of the retina can abstract from the active receptors that absorbed the light quanta. . . . . The anatomical and functional organization of the living system defines a 'point of view,' a bias or a posture from which the interactions take place and that determines the possible relations accessible to the nervous system. . . . Under no circumstance is it possible to associate the activity of any particular cell to any particular interaction of the living system. . . . . .

"The fundamental anatomical and functional organization of the nervous system is basically uniform: the same functions and operations (excitation, inhibition, lateral interaction, recursive inhibition, etc.) are performed in its various parts, although in different contexts and integrated in a different manner. . . . . This basic uniformity of organization can best be expressed by saying: all that is accessible to the nervous system at any point are states of relative activity holding between nerve cells. . . . . Two interactions that produce the same state of relative activity are identical for the nervous system, no matter how different they may be in the cognitive domain of the observer."

We know what we know because the nervous system "can recursively treat its own states of activity as it treats external interactions, and thus remains always able to interact with them and, hence, with itself." We can therefore be self-observing and self-referencing systems, able to behave as inductive systems with an unlimited potential, according to Dr. Maturana, of enlarging our cognitive domain.

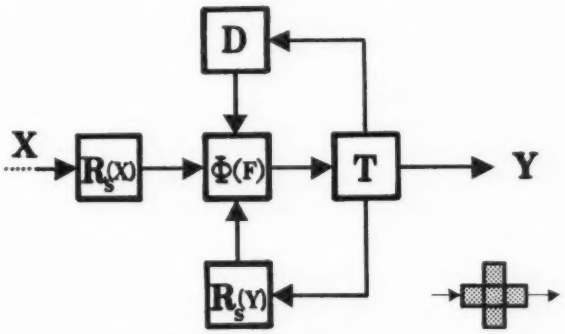


Figure 1. Cognitive element or "tile".

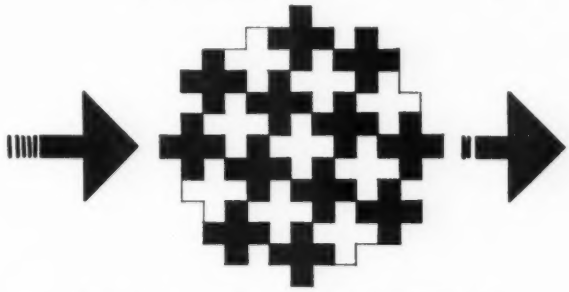


Figure 2. Assembly or tesselation of cognitive tiles.

Dr. Heinz von Foerster, head of the Biological Computer Lab., (4) described a model that incorporates circuitry to account for some of the paradoxes resolved in humans. His cognitive element or "tile" is shown in Figure 1. It represents a minimal case of a cognitive process. X is the external sensory input, and Y the output as seen by an observer. Operations on X produce relations $R_S(X)$ between observed activities with respect to "self" (s); these, rather than X, are the input to a recursive function computer that may be operative at the moment with any one of the functions F belonging to a range Φ. The output from $\Phi(F)$ is fed back over two channels: one, a recursive loop with delay D that allows F to assess its earlier actions, the other carrying all the relational information of the system's own actions $R_S(Y)$ as they refer to "self" and operating on $\Phi(F)$ to update the recursive function computer on the element's internal goals. Two features permit the element to interact with other elements of the same kind. One feature is T that translates into a universal internal language, whatever the output language may be. The other feature is the throughput character of the tile. An assembly of tiles is shown in Figure 2.

The tile's self-referential activity converts incoming signals to information that the tile needs to "know" for its internal representation. Within the assembly of tiles:

> "Information exchange between tiles can take place on all interfaces, however under observance of transmission rules implicit in the flow diagram (of Figure 1). For instance, one tile may incorporate into its own delay loop preprocessed information from an adjacent tile, but eigen-state information of one tile cannot retroactively modify the operations of a 'left' tile, although it can, via its own output, modify that of a 'right' tile, and so on. Although this system exhibits some of the essential properties of cognition as they may be conceptually isolated, e.g., to perceive, to remember, to predict, etc., it is impossible to isolate these properties functionally since it is the interaction of all the processes here involved which 'lift' the information from the input signals and translate them into actions 'meaningful' for the system as a whole."

This is one type of construct anticipated by Dr. Maturana who predicts that artificial cognitive systems can be of two kinds: (1) those whose interactions resemble interactions in the human system; and (2) those whose interactions differ from that humans will have to map into their own. For type (1), it is essential that the artificial system have a *domain of interactions* like the human's, not not a description of it.

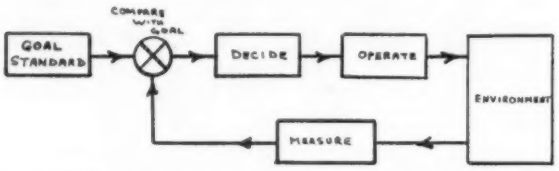


Figure 3. Goal-directed building block or control mechanism.

The teaching machine of Dr. Gordon Pask, head of System Research Ltd., England, and professor of psychology at Brunel University, (5) is another construct. He posits that the elementary unit of a cognitive system is a goal-directed process that must be able to interpret expressions in an object language and make deductions. Goal-directed systems can be reduced to the paradigm represented in Figure 3, or to a collection of such units embedded in and intercommunicating in a suitably structured language illustrated in Figure 4. Though the Figure-3 paradigm refers to a storage medium or "memory," adaptation based on stored information is not learning in Dr. Pask's sense because it does not alter the concepts entertained by the system. The l^0 and l^1 components of Figure 4, the minimal learning unit, each contains an organization similar to that of Figure 3. The distinction between l^0 and l^1 is in the domain and range of their control functions. Control systems in l^0 operate on, and sense the properties of, an environment. Controllers in l^1 operate on and sense the properties of the controllers in l^0, that is, they modify the l^0 repertoire and recognize the

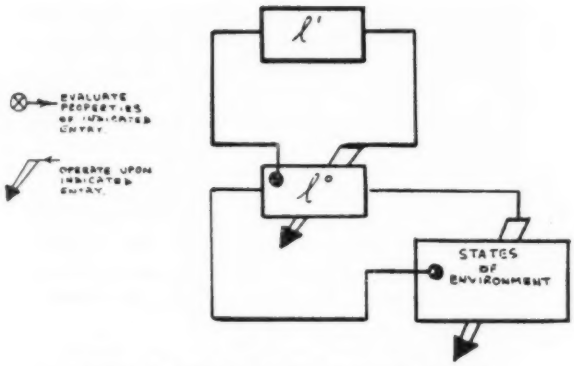


Figure 4. Minimal learning unit or control hierarchy.

overall properties of the l^0 system performance.

Communication, as distinguished from information transfer within the building block for purposes of control, arises when new concepts are produced or old ones are modified.

> "There are just two circumstances in which communication is part of the scheme of things, namely, (1) Systems S_1 and S_2 are competing in the sense that (subgoals) G_1 and G_2 are in some respects not jointly achievable, and (2) S_1 and S_2 cooperate in the sense that G_1 and/or G_2 can be more readily attained (or may only be attainable) if S_1 and S_2 act in concert."

In actual systems, some l^0 concepts exist through inheritance or prior learning; they are used and reproduced through the l^1 component. In the interaction of building blocks, each with different l^0 concepts, existing concepts in the various blocks may become modified. This, combined with the basic reproductive process, engenders new concepts. In the basic learning-teaching situation, the object language L

> "must either be stratified or must contain the apparatus for varying the level of reference of statements, expecially of command statements. Thus, formally, $L = L^0, L^1, \ldots$ Statements at L^0 involve concepts or entire cognitive systems at the level l^0 in an hierarchy of control; statements at L^1 involve l^1 concepts, and so on. According to the process under scrutiny, the systems S_1 and S_2 may be variously interpreted and the levels of discourse with them. Thus, S_1 = learner and S_2 = environment, or, S_1 = student and S_2 = teacher, or, S_1 and S_2 are cognitive subsystems in one and the same physical structure."

Though a possibly realistic unending hierarchy of learning may exist, for practical systems Dr. Pask states that this

> "begs the really important question of where the highest level processes come from. As a hortatory expedient, I propose to truncate the hierarchy at

level I^2. Apart from concepts to do with evaluations, etc., I postulate that I^2 contains a concept of organizational analogy."

Dr. Saul Amarel of RCA's David Sarnoff Research Center (6) reviewed work on problem-solving and decision-making by computer that is in the realm of Dr. Maturana's type (2) constructs. In this realm, computers are envisioned as intellectual aids, and success has been achieved in many areas of engineering and the physical sciences where strong mathematical knowledge has enabled the derivation of appropriate solution algorithms.

"There is an abundance of 'real-life' problems, where either our theoretical knowledge is limited (in many cases it is essentially nonexistent) or for which no acceptable solution algorithms are known. Examples of such problems are: answering questions by making inferences from a body of knowledge, planning and scheduling complex operations, designing large systems, e.g., computers, transportation networks, housing units. For problems of this type, we would like to use the computer in a heuristic mode for the search of possible solutions under the guidance of 'theory-poor' knowledge. . . . . In order to engage the computer in such problem-solving activities, we present it with a problem formulation which is close to the functional form in which the problem appears 'initially' to us. Before presenting the specific problem, however, we must augment the computer's software with a problem-solving procedure for a class of problems in which we choose to embed our problem. Such a procedure must incorporate a collection of special solution methods for the problem class under consideration, and also a set of general methods of reasoning (strategies of problem-solving) that can direct the process of looking for a combination of special methods that will lead to solution. Procedures of this type are usually quite complex, highly conditional, and sensitive to their own operational history as well as to new information coming from their environment; also, justifications for their validity often rest only partly on formal grounds and partly on strong intuitive plausibility arguments. Heuristic problem-solving procedures are from this class and they occupy a central position in current research on artificial intelligence."

In much advanced problem-solving, the solution is an object with considerable internal structure that is synthesized during the problem-solving process from smaller parts. Specification in terms of structural properties resembles the grammatical specification of a language that Dr. Amarel calls the "solution language." The function of a problem-solving system "is to generate a sentence in the language of solutions which is both well-formed, i.e., is constructed according to the grammar of the solution language, and also satisfies the specific conditions of the given problem." Dr. Amarel illustrated the effect that different languages and grammars can have on the efficiency and quality of problem-solving procedures. With his most recently designed language and grammar-generation rules, problem-solving can proceed both forward from sources of information and backward from partial-solution destination nodes in combination with interaction or "closure" rules that establish links between source and destination nodes. Units of "growth" are not prefabricated but are formed during the solution-construction process in a manner responsive to the features of the specific configuration under construction.

Dr. Amarel sees

"no sharp dividing line between the problem-solving procedures of artificial intelligence and the procedures of today's 'conventional' software. It is useful to think that computer procedures lie on some sort of continuum, and each procedure in the continuum is characterized by the relative amount of systematic versus heuristic knowledge available to it, as well as the 'quality' of available knowledge, i.e., the degree to which this knowledge can be efficiently exploited by the manipulative part of the procedure for the solution of specific problems in its domain. At the one end of the continuum, where systematic knowledge is dominant and its mode of utilization is highly efficient, we have the customized procedures that direct most of today's 'useful' work of computers. Next to them, we have problem-solving procedures with deterministic rules of association, elaborate solution blocks, and relatively simple control procedures. As the solution blocks become less elaborate, the control procedures that manipulate them become more complex and heuristic rules begin to emerge. Moving further in the continuum, we have problem-solving procedures with nondeterministic rules of association, whose utilization is controlled, to varying degrees, by heuristic rules. As we reach the other end of the continuum, where the amount of systematic knowledge is low, we have the general, flexible, goal-directed procedures of artificial intelligence, where a set of relatively weak problem-specific principles are combined with several powerful heuristic strategies for the control of search processes."

Central to the design of powerful problem-solving systems is the grammar of the solution language in which problems are represented. At present, upgrading the grammar is a task being performed by people. To enlist the aid of machines, more must be known about methods for the discovery of useful properties in solution languages and procedures for using this knowledge in designing better grammars. Dr. Amarel believes that research of the theory-formation type, of which little has yet been done, will contribute to this objective. The formation problem is more complex, since problem conditions are in the form of properties that the solution as a whole must satisfy, and a solution description must be generated according to rules of a given solution grammar, where no choice of solution element or partial combination of solution elements can be determined directly by the given problem conditions. Ways must be found for bridging the gap between the language of solution structures and the language of conditions.

A problem of the theory-formation type is concept formation. Confluence with anthropologists and anthropo-

logical linguists exists at this frontier. As Dr. Paul L. Garvin of Bunker-Ramo Corp. observed,

> "Most work on artificial intelligence is based on two assumptions that can be quarreled with: (1) that there is a universally human method of problem-solving (the question usually asked is: how does 'a human being' go about solving this problem?); (2) that we know enough about this universally human method to be able to consider its simulation by computer. In my opinion the first assumption is clearly naive: it ignores the well-known facts of cultural variation and individual variability. The second assumption is overoptimistic in spite of well-known efforts to obtain problem-solving protocols."

Dr. Garvin noted that language is an ill-defined system, and "absolute universals are equally ill-defined and allow for a margin of uncertainty." His own computer simulation of linguistic analysis is based on introspection, "a critical examination of the analyst's reasoning and motivation" that lead him to each decision. The informant work being conducted by the anthropologist participants involves building a data base, usually in the form of collections of language strings, from natives in the culture being studied, and evaluating the data base in accordance with a set of hypotheses or rules formulated by the analyst.

Dr. David M. Schneider of the University of Chicago reviewed the state-of-the-art of componential analysis based on its application to American kinship terms and other terminological systems. Componential analysis is a form of semantic analysis in which a vocabulary is established, a record is made of specific images of concepts that informants say an expression may denote, and definitive attributes are extracted through inspection and comparison procedures. Dr. Schneider found that

> "it is not possible to evaluate componential analysis in terms of the usefulness or productivity of its method in view of the extraordinary nature of the extraneously imposed restraints which are imposed on it by its practitioner."

Disagreement among the analytic approaches to kinship terminology arises from differences in

> "(1) what the different semantic domains consist in, and how to discover or establish them; (2) the relationship between the different domains insofar as the words or kinship terms are concerned; and (3) whether it follows from polysemy that a given word has only one 'basic' or defining or significational meaning deriving from one domain (all others being either extensions, metaphors, synonyms, or homonyms) or whether a different significational meaning can be demonstrated for each semantic domain, or just how the different meanings of a word are hierarchically arranged, if they are."

Dr. Benjamin N. Colby of the University of California, Irvine, reported on his studies of folk narratives. He suggests that a grammar of narrative culture have three parts:

> "(1) morphological components which make up the essential skeleton of a narrative; (2) poetic and stylistic components dealing with the fleshing out of the narrative; and (3) the highlighting structures for the dynamic effectiveness of the folktale as a psychic device and culture vehicle. Hopefully, progress in the third section will point to a fourth type of structure: functional patterns in folk narratives."

Dr. Colby anticipates that, after enough grammars are written, comparisons will show extensive regularities that may sharpen our knowledge of culture and culture boundaries.

> "Anthropologists often speak as though broad cultural patterns are easily derived in good ethnography, but what they usually refer to are normative statements about behavior. Attempts to go beyond this, as in Ruth Benedict's *Patterns of Culture*, have so far been entirely intuitive and are quickly disputed. The great exceptions, of course, are in linguistics and kinship where true patterns clearly exist. It now appears that we are on the verge of a new area in culture study where a variety of demonstrable patterns can be discovered, tested and confirmed. While linguistics and kinship have not lived up to our earlier hopes for a point of entry to the infrastructure of nonkin and nonlinguistic behavior, we may have another chance through the analysis of narrative culture."

Problems of language appear to be the ties that bind. For artificial intelligence, appropriate languages are needed for problem-description and solution procedures and for characterizing the performance of cognitive systems. For anthropology, uniform methods of analyzing and interpreting language appear desirable for ethnoscientific, psycholinguistic, and machine manipulation purposes. The value of the Wenner Gren Symposium, to this reporter, is that it was effective in exposing these common-bond areas to both groups of participants. Both are searching for an understanding of cognitive processes and ways of formally recognizing and expressing them. Artificial intelligence may be expected to contribute increasingly refined methods of representation and algorithmic procedures. Anthropology and linguistics will be structuring data bases, discovering patterns and regularities in them, and clarifying exceptions. It is probably inevitable that the rapprochement begun at this Symposium will grow because of the value of the products of each group to the other.

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(1) Symposium Chairmen were Dr. Paul L. Garvin and Dr. Heinz von Foerster. The Symposium was held in the Center for Continuing

Education, on the University of Chicago campus. The *Proceedings* will be published.

(2) Research sponsored under AFOSR Contract AF 49(638)-1680.

(3) Lettvin, J. Y., H. R. Maturana, W. S. McCulloch and W. H. Pitts, "What The Frog's Eye Tells the Frog's Brain," *Proceedings of the Institute of Radio Engineers*, Vol. 47, No. 11 (1959), 1940-1951.

(4) Research sponsored under AFOSR Grant 67-007B.

(5) Research sponsored under AFOSR Contract F61052-67-C-0010.

(6) Research sponsored under AFOSR Contract F44620-68-C-0012.

Air Force and Army Cooperation in Bitter Weather Produces a Precise Geodetic Measurement

OWEN W. WILLIAMS, Terrestrial Sciences Laboratory, AFCRL

During the past decade, scientists of the Terrestrial Sciences Laboratory of AFCRL have developed and used a 50-kilometer optical test base line (or range) between our Laboratory in Bedford, Massachusetts, and the top of Mt. Wachusett in central Massachusetts. The test and calibration of newly developed geodetic instrumentation, such as artificial-earth-satellite flash lamps and satellite laser ranging systems, has been undertaken over this test range.

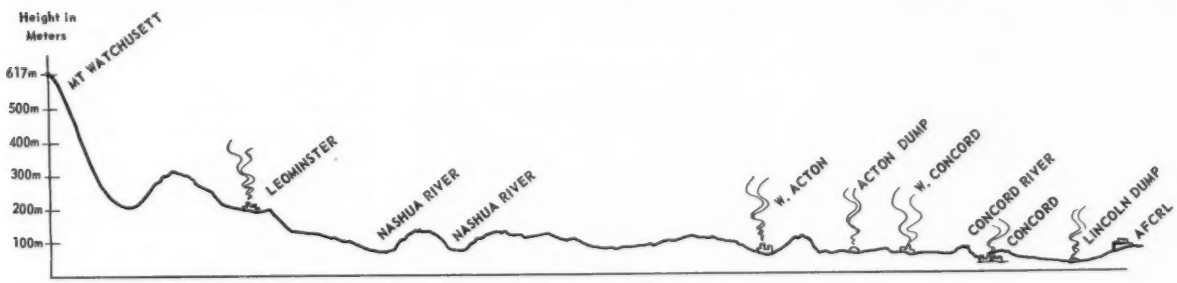
Although the range has been ideal in providing many conditions found in normal geodetic operations, the length of the line and the path of the line (which is continually hampered by haze and smoke) have presented a major problem in producing an extremely accurate measurement of the distance of that line. For several years that distance, as derived and computed from the existing first-order triangulation, has been acceptable for AFCRL tests. The computed distance of the line is accurate to one meter.

However, as our scientists began the development and test of satellite laser ranging devices, it became apparent that a more accurate measurement of the line was needed to permit the precise calibration of unique instrumentation. Attempts since 1966 to improve the accuracy of the line by direct measurement have been defeated by the combination of distance, haze, smoke and other environmental conditions. (See Figure 1)

During a coordination meeting held in 1968 between the Terrestrial Sciences Laboratory and the Research Institute, U.S. Army Engineer Topographic Laboratories (now a part of the U.S. Army Topographic Command), it was suggested that a newly developed Army apparatus known as a high-precision laser Geodolite be used to measure the base line. Thus, in late January 1969, five men from the Research Institute and AFCRL attempted the measurement from the AFCRL geodetic observatory to a bank of retroreflectors located on top of Mt. Wachusett during an extremely clear but brisk night when temperatures hovered about the 0°F. mark. An inadequate signal strength received at AFCRL from the retroreflectors caused the round-trip range measurement to fail. Further attempts were delayed by bad weather.

When a clear weather prevailed again on February 5th, a Research Institute scientist, Kenneth Robertson, completed the measurement that night, with temperatures ranging from 10° to 15°F. The line was measured with an accuracy of three parts in a million (3×10^6) or .15 meter.

Technical complications and logistic problems created by snow, ice, and bitter cold made the task difficult. However, a cooperative effort between Air Force and Army scientists assured its success. We are grateful for the assistance provided by Dr. Desmond O'Connor and Mr. Kenneth Robertson of the Army Engineer's Research Institute, and Captain Darwin G. Abby, Mr. Theodore E. Wirtanen, Mr. Robert L. Iliff, and SSgt Gerald O. Smith of AFCRL in completing the task.



ELEVATION PROFILE

Figure 1

TERRESTRIAL SCIENCES LABORATORY AFCRL

ultraviolet sensing: guide to exploitation

Ultraviolet (UV) sensing is at about the same state of development reached by infrared sensing 20 years ago. UV sensing could prove as militarily useful as infrared sensing, but its effective application requires much more knowledge and understanding than we now have. Many physical constraints, particularly ozone absorption, still bar its widespread application. Profitable areas of research are the reflection, absorption, and polarization of ultraviolet radiation by the surfaces of soils, vegetation, and man-made materials, and the study of the characteristics of UV sky and solar radiation in a variety of environments.

This is the substance of a survey report, "Ultraviolet Radiation and the Terrestrial Surface" (AFCRL-68-0572), by J. F. Cronin *et al* of AFCRL. The report reviews the little research that has been done and is being done relating to UV sensing, and covers such matters as the ozone-absorption problem, the reflectance properties of terrestrial surfaces, instrumentation, and the military usefulness of UV devices.

The UV region of the electromagnetic spectrum extends from 4,000 to 100 angstroms, and lies between the visible and the X-ray regions. The primary source of illuminating energy used for remote sensing is the sun; but only a small fraction of the UV energy from the sun penetrates the earth's atmosphere. Of the total solar UV radiation, only the longer wavelengths—practically none shorter than 2,900 angstroms—reach the earth. The solar UV radiation that does reach the ground, however, is fairly constant, varying only as the distance of the earth from the sun varies in the earth's annual orbit. This variation is only about plus or minus 3 percent.

The aphelion-perihelion variation is not nearly so marked as variations in the amount of solar UV radiation reaching the ground because of different ozone concentrations surrounding the earth. Although other atmospheric gases absorb energy, none does so as effectively as ozone. At mid-latitudes, concentrations of ozone may vary seasonally by plus or minus 35 percent; and within any given month variations may average plus or minus 15 percent at any given latitude. These changes in the levels of ozone concentrations are not always predictable. Strong atmospheric absorption makes it unlikely that surveillance satellites or earth-resources satellites of the ERTS or EROS types will ever carry UV sensors for monitoring terrain features. This is because the solar UV energy must not only penetrate the atmosphere to the ground, but also make the return transit to the satellite sensor. The energy would be thoroughly attenuated.

Very little can be done to cope with the atmospheric absorption problem, except to understand the limits set by atmospheric absorption on sensor design. But much remains to be done to improve our comprehension of UV optical properties of a multitude of organic and inorganic materials. Data must be gathered not only on a range of different materials, but also on the near-infinite forms that a given material takes. For example, UV studies of the microrelief of a natural surface, and of such variables as grain size, shape, and orientation, are almost totally lacking. The cellular structure of foliage can change greatly during rainy and dry periods; and UV detectors respond quite sensitively to these changes. An area almost wholly ignored concerns the reflectance properties of microorganisms which can thoroughly pervade some soils and which can dominate UV reflectance properties. Not only must these various properties be measured, but they should also be measured as a function of solar angle, which is sometimes the most critical parameter.

Some of the approaches to improved instrumentation involve the use of more sensitive UV photometers, photographic films with better UV response, or such advanced and sophisticated techniques as the Fraunhofer line-depth method of UV detection.

Even though much research remains to be done, the authors of the AFCRL report foresee many potential military applications, ranging from vision enhancement of the foot soldier to surveillance by low-altitude airborne sensors.

Dr. Thomas P. Rooney (left) and Mr. John F. Cronin examine a recording showing the attenuation of ultraviolet radiation in the atmosphere.

Dr. Thomas P. Rooney is a general research physical scientist at the Geotechnics Branch of AFCRL's Terrestrial Sciences Laboratory. He received his B.S. in Geology from the City College of New York in 1959, and in 1962 and 1965, respectively, received his M.S. and Ph.D. in Geology, both from Columbia University.

Dr. Rooney was formerly employed as a research scientist at Columbia University. He is presently conducting research on the diffuse reflectance properties of rocks and the mineralogy of playa lake sediments.

Dr. Rooney is a member of the Geological Society of America, the Mineralogical Society of America, the American Association for the Advancement of Science, The American Crystallographic Society, Sigma Xi, and RESA.

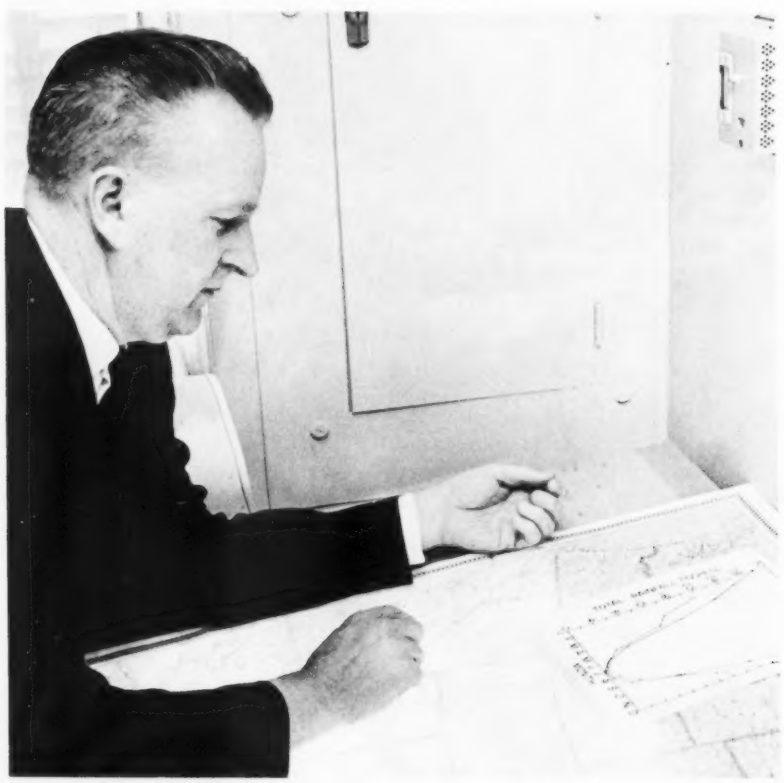
Mr. John F. Cronin is a physical scientist at the Geotechnics Branch of AFCRL's Terrestrial Sciences Laboratory where he is responsible for determining the geological significance of photography and other sensor imagery obtained from satellites or from platforms at extremely high altitudes. His recent work has involved a study of the infrared radiometric data from selected orbits of TIROS, the development of multiband photographic techniques, and the interferometric measurements of terrestrial materials.

Mr. Cronin was formerly employed as a province geologist with the Shell Oil Company, and as a research geophysicist with Allied Research Associates, Inc. He received his Ph.B. from the University of Chicago in 1941, and his B.S. from the University of Chicago in 1948. He has also studied at the University of California at L.A.

Mr. Cronin is a member of the American Geophysical Union, the Geological Society of America, and the Optical Society of America.

APRIL IN THE SAN JOAQUIN AND SACRAMENTO VALLEYS

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL



Iver Lund examines a plot of average rainfall over a year's period in the San Joaquin and Sacramento Valleys.

Mr. Iver A. Lund is a research physicist at the Design Climatology Branch of AFCRL's Aerospace Instrumentation Laboratory. He received a B.A. degree from the State College at Dickinson, North Dakota in 1941. He also attended the California Institute of Technology from which he received the M.S. degree in Meteorology in 1943.

After military service with the Army and Army Air Force during World War II, Mr. Lund taught high school science and mathematics in North Dakota and California. He was also on the Research Staff of the California Institute of Technology, and was later a research meteorologist with the American Institute of Aerological Research.

Mr. Lund has been with AFCRL from 1951 up to the present. He has concentrated on developing techniques for predicting terminal weather, and utilizing predictions when making operational decisions. He developed a new technique for estimating the probability of future events. This technique consists of employing a mathematical device for transforming predictors into essentially independent variables, and using Bayes Theorem to estimate the probability of a future event. This method was one of only five objective terminal forecasting methods selected by Weather System 433L for further testing.

If it is possible to predict a few weeks in advance the onset of the monsoon season in Southeast Asia—which Iver Lund of AFCRL has endeavored to do—why shouldn't it be possible to use similar methods for predicting rainfall elsewhere? Lund has shown that this is possible for a locality that has distinct wet and dry seasons.

In the United States, the localities that best meet these criteria are the San Joaquin and Sacramento Valleys in California. Taking a 30-year average, the total rainfall observed at 10 stations in these Valleys is less than an inch during July and August, while the average January total rainfall is 30 inches. But we are not interested in predicting January or July rainfall since we already know that, barring some gross anomaly, January will be wet and July will be very dry. If we take the month of April, however, between the two extremes, we find that, although the 30-year average rainfall is about 15 inches, the amounts falling from year to year range from less than an inch to more than 37 inches.

The question then is: "Can we predict well in advance whether or not the month of April in the two California Valleys will be wet or dry?" Lund, using observations of the atmosphere over a widespread geographical area, has shown that such a prediction is possible, with the extent of predictability being about two weeks in advance.

Lund's study, which is basically statistical, relies on existing records over a 22-year period covering large geographical areas in the eastern United States, northern Canada, and southwestern United States. Of primary interest are wind circulations at 5 atmospheric pressure surfaces—200, 300, 500, 700 and 850 mb—which correspond to altitudes of 40,000 down to 5,000 feet. Although the study involved correlations and regression techniques taking into account a number of possible predictors, Lund found that, as in his earlier monsoon studies, atmospheric circulations in the upper regions of the atmosphere are the clearest precursors

of future rainfall—at least for April rainfall in the San Joaquin and Sacramento Valleys.

Of the three geographical areas studied that may influence April precipitation in central California, circulations at the 200-mb region over north central Canada were the most significant, although there was also a high correlation with circulations at the 850-mb level over southwestern United States. Sea-level circulations yield few clues to future rainfall.

As a measure of the effectiveness of the extended range prediction scheme based on upper-air circulations, Lund has plotted observed April rainfall for a 22-year period, and has compared these observed values with predicted values. The accuracy for the 5-year period, 1963 through 1967, is particularly striking. In 1963, the predicted and observed values were both 34 inches; in 1964 the values were 8 and 4 inches, respectively; in 1965, both were 25 inches; in 1966, both were 3 inches; and in 1967, the values were 33 and 35 inches, respectively.

The reason that it is possible, at certain times of the year, to make extended range predictions based on upper-air circulations is that large changes in the character of the planetary circulation occur between winter and summer. The influences of these changes may be felt many miles from where the circulation shifts occur. Because the atmosphere is sluggish, some time must elapse before the terrestrial environment is influenced by these geographically remote atmospheric circulation changes. This permits a basis for prediction.

SOLID-STATE JUNCTION STRESS

CAPT JOHN F. KANTAK,
Directorate of
Engineering Sciences, AFOSR

The development of a new experimental technique to observe the effects of dynamic stress on semiconductor junctions has expanded solid-state mechanical sensor research. The new methodology employs a metal-oxide-semiconductor (MOS) junction acted upon by a mechanism capable of inducing large mechanical forces in the junction. The scientific community has known for over a decade that large mechanical forces can produce significant reversible changes in the electrical properties of semiconductor junctions. However, due to the nonlinear character of this behavior, the present state-of-the-art has been derived solely from static stress research. Dr. J. J. Wortman at Research Triangle Institute, Raleigh-Durham, North Carolina, is presently studying the stress-induced piezojunction phenomenon (1) under the sponsorship of AFOSR. He has developed a theoretical model and an accurate experimental technique to investigate the response of the junction to dynamic stress stimulus.

Initially, Dr. Wortman designed a stress wave generator that subjects p-n junctions to large dynamic forces by electromechanically driving, with a sinusoidal source, a cantilevered silicon beam into which p-n junctions have been diffused. Stress levels up to 50,000 pounds per square inch have been obtained at a variety of beam resonant frequencies (20-1000 Hz). The stress levels in the junctions are both measurable and calculable, and the data are presented as one cycle of the output current for constant voltage and a variety of stress magnitudes

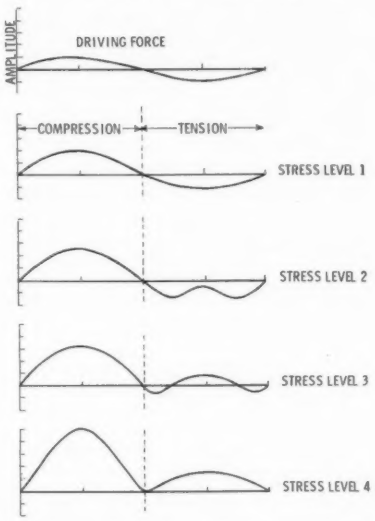


Figure 1. Junction current with increasing stress.

(Figure 1). Data analysis provides information on band edge movement, energy gap changes, and carrier mobility and density. The current-stress

plots clearly indicate an asymmetry in junction current response to compressive and tensile forces. Increasing compressive force creates a monotonic increase in junction current. However, increasing tensile force first causes a decreasing current; then, as the force magnitude continues to increase, the current reverses and increases. This is the first time this type of tensile stress performance has been observed. Although the current-stress characteristics provide great insight into the physical nature of the piezojunction phenomenon, second-order effects cannot be evaluated by this technique alone.

The definition of specific electrical properties related to dynamic stress is extremely important to both a complete understanding of the phenomenon and the design of practical devices based on the phenomenon. For instance, gold-doped silicon junctions operated in the reverse bias mode have been found to be more sensitive to stress than nondoped junctions. Gold is used to control carrier lifetime in semiconductors (acting as a trap), and has been chosen as the impurity center for studies of the effect of carrier lifetime on the piezojunction mechanism.

To obtain the required stress-dependent data, Dr. Wortman has developed a new experimental method based on the transient MOS capacitance technique proposed by Heiman (2) and Hofstein (3). The new technique involves a correlation of the transient change in the capacitance of an MOS capacitor (Figure 2) subjected to dynamic stress, with the carrier generation by the recombination centers (gold) near the surface of the semiconductor substrate.

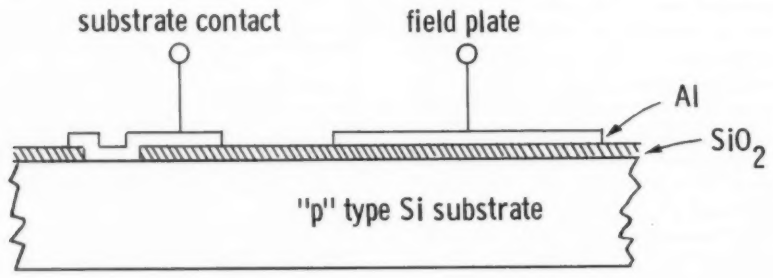


Figure 2. MOS capacitor.

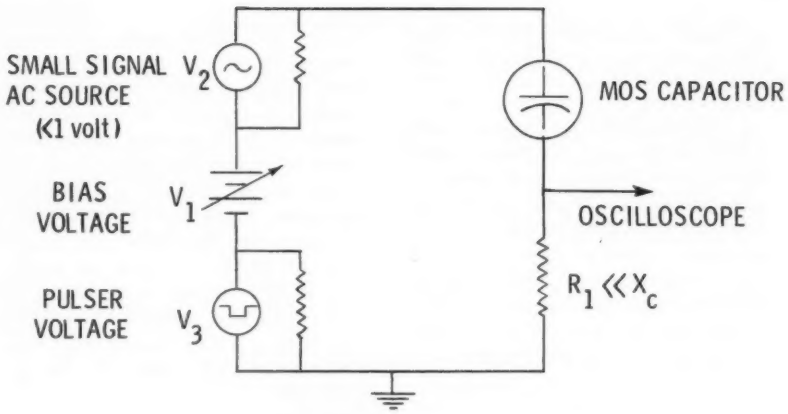


Figure 3. Capacitance--measurement circuit.

MOS devices (20 x 30 mils) are realized on a large silicon wafer 2 mils thick. The wafer is then etched into many small chips (100 mils square) containing 4 to 6 MOS capacitors each. The chips are then epoxy-mounted onto a cantilevered spring steel bar. The free end of the bar is caused to oscillate in the vertical plane by applying a time-varying force (4), thereby inducing both compressive and tensile stress in each of the MOS devices.

The electrical properties of each device are monitored by the circuit shown in Figure 3. The capacitance-voltage (C-V) characteristic of a typical p-type MOS capacitor for a slowly varying bias voltage is shown by the solid curve of Figure 4, while the dotted curve depicts the junction response to a rapidly changing bias voltage.

It is instructive to discuss the experimental operation in the light of Figures 3 and 4. The initial operating point of the MOS capacitor is set at

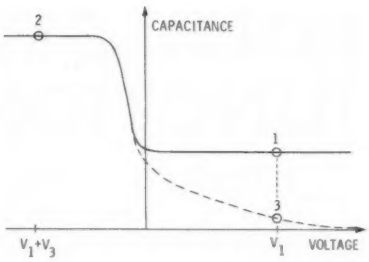


Figure 4. Capacitance-voltage operating curve.

position 1 on the C-V curve by the d-c bias voltage V_1. The small amplitude high-frequency (100-500 KHz) source V_2 allows observation of device capacitance alterations. The pulser voltage V_3, of sufficient amplitude and proper polarity, is applied across the device to move the operating point to position 2 on the C-V curve. The transition is effected by drift and diffusion mechanisms in less than 1 microsecond. When the pulser voltage V_3 returns to zero, the d-c bias across the device is provided solely by the normal bias source V_1. The rapid reduction in bias voltage initiates another drift-diffusion process ($\simeq$ 1 microsecond), and the device capacitance switches very quickly to position 3 on the C-V curve. The rapid switching between operating points creates a large depletion region that borders the oxide surface of the capacitor substrate. Since normal stimuli are again present, the device will change from operating position 3 back to position 1, thus removing the induced depletion re-

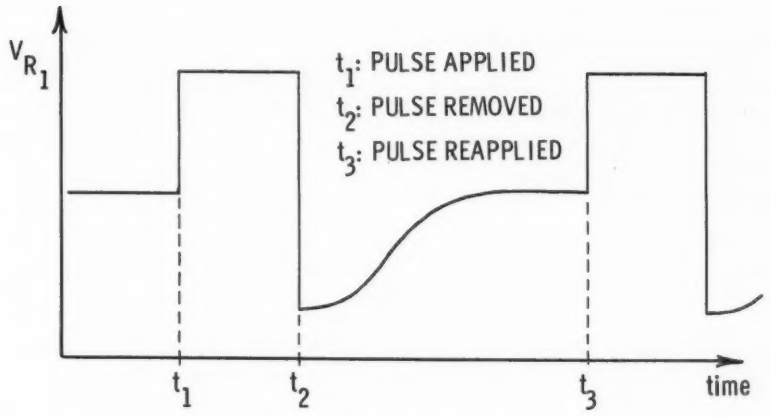


Figure 5. Capacitance-time curve.

gion. Since the oxide-layer leakage current is negligible, the only available carrier sources are the recombination centers located near the surface of the substrate. As the carriers are generated, the device capacitance returns to position 1 in approximately 0.1 to 100 milliseconds, and the depletion layer is eliminated. The change in device capacitance which accompanies the disappearance of the depletion layer in the substrate is monitored by recording the voltage across R_1 (Figure 5).

The carrier generation process is a thermal mechanism that is described using Boltzmann statistics, so that the time associated with the transition from position 3 to position 1 can be plotted logarithmically as a function of $(kT)^{-1}$ The slope of the plot is the energy level of the generation mechanism, and the abscissa intercept defines the product of the number of active centers and the capture cross section of the recombination centers. The data can be further analyzed to directly define carrier lifetime. The transition times between the MOS device operating points can be at least two orders of magnitude faster than the frequency of the oscillations causing the stress forces, so that many data points may be obtained during each half cycle of compressive and tensile stress. All data are collected at a variety of stress magnitudes such that the stress dependence of each parameter is readily obtained.

This AFOSR-sponsored research represents a significant step toward a complete understanding of the piezojunction effect induced by dynamic mechanical forces. The data provide the first quantitative description of tensile stress influence on the electrical properties of junction devices, and are invaluable to solid-state researchers studying band edge point degeneracy and deformation potentials. From a practical viewpoint, the precisely defined electrical properties provide tools heretofore inaccessible for the analytical description of device performance, hysteresis and stability analysis, and sensitivity evaluation.

The results provided by this new research technique are being immediately exploited in three specific areas: (1) the AFSC Avionics Laboratory is sponsoring Dr. Wortman's investigation of the piezojunction effect for application in transducers that will be compatible in size, power requirements, and technology with integrated circuits; (2) NASA-Langley is sponsoring the search for a miniature, highly sensitive pressure sensor for meteorological exploration; (3) Dr. Wortman has proposed the study and measurement of stress levels and effects in semiconductor junctions resulting from nuclear-weapons events. Nuclear-weapons events create the class of problems described as transient radiation effects on electrical systems (TREES), considered to be among the most prominent current technological areas of interest.

The increased research capability and the obvious applications have motivated the search for other materials that exhibit a higher stress sensitivity than silicon. One of the most promising candidates is the class of materials known as organometallic long-chain polymers. These materials are unique in that one crystal axis acts as a semiconductor, and the electrical properties along the axis can be tailored by adding different ligands to the molecules. Dr. Wortman and Dr. L. Montieth are presently investigating dicarbonylpentan-2,4-dionatorhodium in crystal form. This material has the potential of being six orders of magnitude more pressure sensitive than silicon.

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MANTLE AURORA

IONOSPHERIC PHYSICS LABORATORY, AFCRL

AFCRL scientists have photographed for the first time an unusual auroral phenomenon. Although the existence of this auroral form was first suggested a decade ago, little is known of its dimensions or characteristics—and there has been some uncertainty as to whether it is in fact a distinct auroral form or not.

There are several types of aurora, each having a marked structure—auroral curtains, rayed bands, and so on. The novel auroral form observed by AFCRL (photographed by Robert W. Gowell) is unstructured and manifests itself as a marked brightening of uniform luminosity of the entire sky. The luminosity occurs as irregular pulsations, with each pulse lasting about a minute. Past evidence of their existence has been based on photometer data. The faint luminescence of the sky, which appeared to be wider than the visible forms, has been termed "mantle aurora."

AFCRL obtained its unusual photographic records by being in the right place at the right time. The right place was the point reached by an AFCRL KC-135 flying laboratory, flying at 30,000 feet within the auroral oval along a path off the east coast of Greenland. The right time was shortly after midnight (local time) on December 7, 1967.

The KC-135 carried an all-sky camera having a 160-degree view angle. For a 2½-hour period, from 0600 to 0831 UT, 15-second exposures were made at 1-minute intervals. Sky-brightness variations were most clearly observed in the period from 0612 to 0652 UT when the last distinct pulsation was observed. Pulsations appeared to continue until 0800 UT, but highly structured auroras, also present at that time, contaminated the photographic data. The novel aurora was too faint to be observed with the unaided eye. Gowell believes that layers of ice crystals in the troposhere might have prevented an Arctic ground station from obtaining a photographic record of this faint mantle aurora.

The photographic data show that, after a total brightening of the sky occurred, the brightness receded toward the north, occasionally disappearing altogether. More often, the northern half of the sky remained bright after the southern half darkened. Gowell believes that the pulsating brightness results from a fluctuating precipitation of energetic particles over an extensive area.

The "auroral oval," a concept which has developed from both observation and theory, encircles the magnetic pole as does the auroral zone. However, the auroral zone is fixed with respect to the earth, whereas the auroral oval's large axis is fixed with respect to the sun, with the earth rotating below. The position of the oval, if plotted on a map, changes from hour to hour, and indicates where the aurora occurs at a particular time. Current scientific interest in the auroral oval is closely associated with interest in the solar wind and the magnetosphere. The Arctic ionosphere, which is subject to particle precipitation, serves as a "looking glass" for the study of the mechanisms of magnetospheric plasma movements.

AFCRL's photographic record of the mantle aurora is a by-product of an AFCRL flight along the auroral oval to measure its radio and optical properties. In a research note, which Gowell coauthored with Dr. S. I. Akasofu of the Geophysical Institute of Alaska, soon to be published in *Planetary Space Science*, Gowell will report in greater detail on his photographic record.

Mr. Robert W. Gowell is an electronics engineer at the Ionospheric Radio Physics Research Branch of AFCRL's Ionospheric Physics Laboratory. As overall manager of instrumentation performance of the KC-135 project aircraft, Mr. Gowell provides technical guidance to the operators and works with scientific personnel to improve the instrumentation for data handling and reduction.

Mr. Gowell attended Massachusetts Radio School in 1950. In 1958, he received an EE Associates degree at Northeastern University Evening Engineering School. From 1960 to 1968, he attended various collegiate, commercial, and Governmental courses related to his work.

From 1950-1953 Mr. Gowell worked as a station engineer for WEIM Broadcasting, Inc. at Fitchburg, Mass. and, from 1953-1956, was an electronic technician with AFCRC (predecessor of AFCRL). After a year as an engineering aid with Barkley and Dexter Laboratories in Fitchburg, Mass. (1956-1957), he returned to AFCRC/AFCRL where he has remained up to the present.

Mr. Gowell has coauthored several articles, and has a patent claim pending.

Robert W. Gowell examines the all-sky camera with a 160-degree lens which he used to photograph for the first time a novel auroral phenomenon known as the mantle aurora.

a convenient and revealing treatment of plasma oscillations

DR. DAVID A. LEE,
Applied Mathematics
Research Laboratory, ARL

Efficient controlled thermonuclear fusion, if it could be achieved, would create an almost inexhaustable energy supply; even a relatively inefficient fusion device might be useful for propulsion. These facts have spurred many fusion-oriented research projects. All devices constructed to date have depended on the noncontaminating, nonquenching confinement of a hot, dense plasma, and all have failed because of the effects of various plasma instabilities.

At present, it appears that if one had a complete understanding of plasma instabilities, particularly microinstabilities, which are fluctuating changes in the energy distribution of the plasma's particles, one might very well be able to design a successful fusion machine. In consequence, many theoretical plasma instability projects are under way in conjunction with each fusion machine project. An important goal of each such project is to make an exhaustive catalogue of the plasma instabilities that might affect the device in question, and to determine, by computing growth rates, propagation behavior (i.e., absolute or convective character) and the reflection characteristics of each instability, which ones are most threatening, and how to circumvent their ill effects.

Clearly, the Air Force has a strong interest in the technology that may ultimately result from the fusion-oriented basic research now in progress in high-temperature plasma physics. Two members of the ARL Theoretical High-Temperature Plasma Physics Research Group, Dr. David A. Lee of the Applied Mathematics Research Laboratory and Dr. Gordon K. Soper of the Department of Physics, U.S. Air Force Institute of Technology, have recently published (1, 2, 3) a new formulation of certain basic microinstability problems. Their treatment reduces the problems to the solution of integral equations of a kind that has received a good deal of attention from mathematicians. Thus, there is already available a large body of mathematical results which may bear on physical questions, when properly interpreted. The new formulation lends itself readily to numerical solution, and has the advantage that results are obtained directly for measurable quantities themselves rather than for their integral transforms, as is the case with other treatments. Rather surprisingly the new formulation, in some cases of interest, leads to solutions that can be written in closed form in terms of well-known functions, which are very convenient for physical interpretations. For example, in the classical Landau problem one considers an approximation to the effect of a disturbance on a plasma initially in equilibrium. Classical treatments of the problem lead to the conclusion that, in general, the disturbance is damped—even if collisional effects are neglected—provided the equilibrium electron distribution function is a nonincreasing function of electron energy.

But an exact solution for a certain class of problems, readily obtained from the integral equation formulation, reveals the nature of the plasma's response more clearly. For this class, the disturbance in electron number density initially has the form

$$\frac{L\ N_0}{(X^2+L^2)\,\pi^2}$$

At later times, the disturbance takes the form

$$\frac{N_0(L+V_0t)}{\pi^2\ [(L+V_0t)^2+X^2\ ]^2}\ \cos W_0 t.$$

It is evident from the second expression that the noncollisional damping is not particularly mysterious—the disturbance maintains its initial form, while its characteristic length, L, increases with time at the electron thermal speed, V_0, causing the amplitude of the disturbance eventually to decrease at all points of the plasma. The entire disturbance also oscillates at the electron plasma frequency, W_0.

This example illustrates that a particular advantage of the method is that physical insight is carried through to the final solution. It is therefore possible to use experimental results to guide and structure the analysis more readily than with some other techniques. Further analytic and numerical work is being done to apply the method to nonlinear problems and to problems with externally applied fields.

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Dr. David A. Lee has been a civilian research mathematician at the Applied Mathematics Research Laboratory, ARL, since February 1966. He has been conducting research on applications of analysis to problems in turbulence and plasma theory.

Dr. Lee earned his Bachelor's degree in Electrical Engineering in 1959 at the University of Missouri, at which time he also received his commission in the Air Force Reserve. Subsequently, in 1961, with Danforth and Woodrow Wilson Fellowships, he received his Sc.M. degree in Applied Mathematics at Brown University, and in 1963 was awarded his Ph.D. in Mechanics by the Illinois Institute of Technology.

Dr. Lee was first assigned to ARL in 1963 as an Air Force officer. He continued his academic research in the theory of inhomogeneous turbulence and collaborated on a study of moving striations in positive columns of DC discharges. He has published several articles in scientific journals.

Investigation of Supersonic Low-Density Air Ejector System

FRED L. DAUM, Fluid Dynamics Facilities Research Laboratory, ARL, and
JOSEPH S. SHANG, Hypersonic Research Laboratory, ARL

A rarefied gas-dynamics research project was initiated at ARL to study the impact pressure behavior in low-density hypersonic flow. (1) An analysis of the flow requirement indicated that the existing ARL 5-inch hypersonic blow-down wind tunnel was not capable of simulating the needed low-density flow conditions. The requirement for low-density flow conditions in the test section demands a low stagnation pressure. However, the maintenance of fully developed hypersonic flow through the wind-tunnel nozzle also requires a specific pressure ratio across the nozzle-diffuser system. In the present case, the minimum operational stagnation pressure did not give the desired low-density test-section flow. Therefore, a study of air-to-air ejector systems was begun with the intent of applying an air ejector to augment the wind-tunnel vacuum-pump capability, and thereby lowering the attainable back pressure which in turn would provide the required pressure ratio.

A survey of available pumping equipment revealed that a major facility modification could be avoided by using a low-density, supersonic, air-to-air ejector to augment the capability of the existing pumping facility. Also, such ejectors could be used in multiple stages to obtain very low working densities. However, the design of ejector systems is not very straightforward, and is more of an art than a science. This is because of the complications encountered in trying to analyze the flow conditions through the ejector, particularly when it comes to accounting for the mixing processes and momentum exchange between the driving and the driven flow. Therefore, a brief study was made of a single-stage air-to-air ejector with plans to

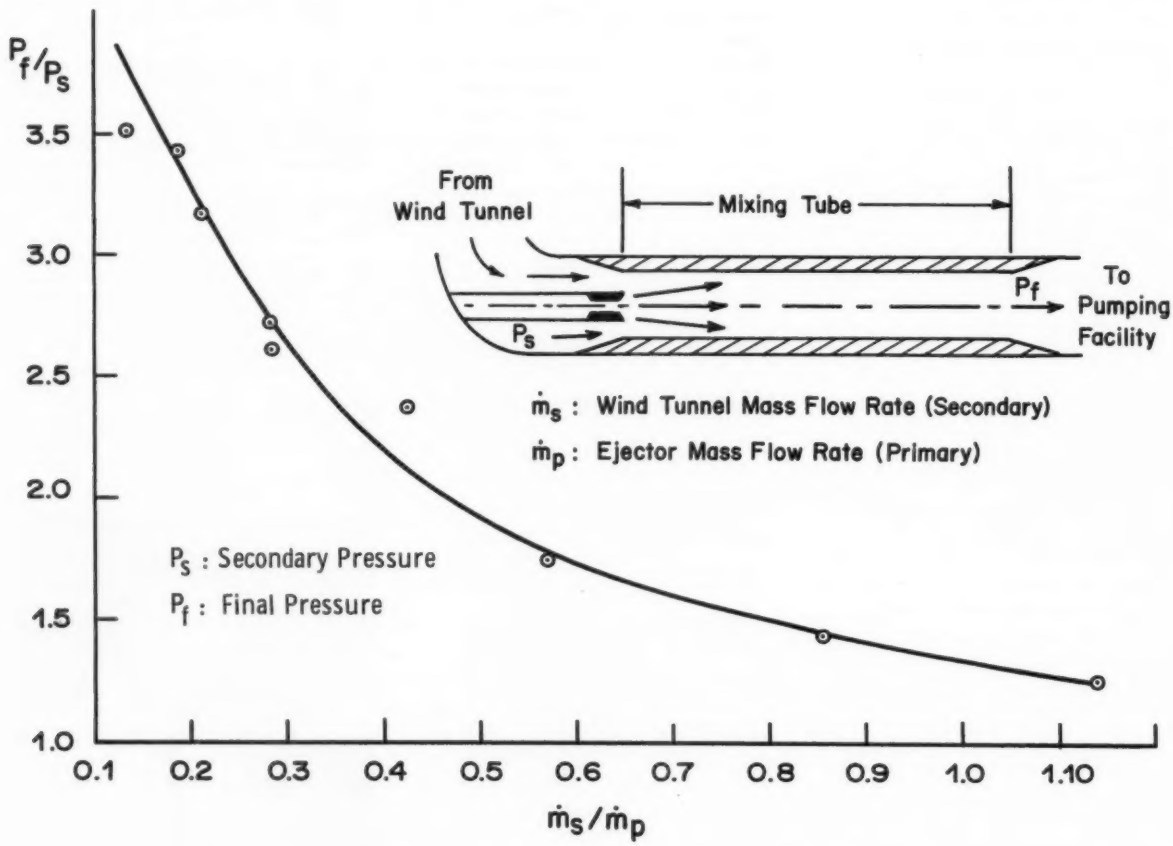

Figure 1. Effect of mass-flow ratio on ejector pressure ratio.

also investigate a 2-stage system, if necessary.

The general arrangement of ejector configuration is sketched in Figure 1. Unfortunately, the only practical location for the ejector was at a 90-degree bend in the pipe; this location provided for possible subsequent installation of a second stage further downstream. Three simple conical ejector nozzles were fabricated for generating the high-speed primary flow: one design was for Mach 7, and each of the others delivered Mach 5; but there was a factor-of-4 difference in scale between these two nozzles.

Another geometric variable investigated was the axial position of the primary jet nozzle relative to the entrances of the mixing tube. The pumping performance of the ejector was studied over a range of secondary mass flows starting at zero and covering the normal wind-tunnel operational mass-flow range. The primary mass flows were varied systematically with the secondary mass flows. For investigating the mixing-tube flow characteristics, the axial static-pressure distribution along the ejector wall was measured, and a probe was prepared for making impact-pressure surveys across the mixing streams.

It was learned that, for all driving-jets tested and for the range of axial movement provided, the position of the ejector nozzle had little effect on the overall ejector performance. The Mach-7 ejector nozzle performed better than the other nozzles, and the mass-flow characteristics were more favorable.

Since the effectiveness of the ejector in decreasing the wind-tunnel-nozzle back pressure (the pressure downstream of the wind-tunnel hypersonic diffuser) is of primary concern here, a plot is presented in Figure 1 to illustrate this performance. It shows that, through the use of the ejector, the tunnel back pressure may be decreased by a factor of about 3.0. It is also apparent that the primary mass flow becomes significantly greater than the secondary mass flow in order to achieve the lowered back pressures. However, for this application the ejector is used primarily for low stagnation pressure and, therefore, low secondary mass-flow rates; the absolute primary flow rate is actually small and does not create a problem for the wind-tunnel vacuum pumps.

It was found that, for the purpose of the rarefied gas-dynamics studies concerned, (1,2) the single-stage ejector was sufficiently effective to provide the desired operating wind-tunnel conditions. Therefore, the study of the two-stage ejector was not made at this time.

Through the application of this ejector, it was possible to lower the minimum wind-tunnel operating stagnation pressure from about 100 psia to 20 psia, while obtaining a nominal test Mach number of 14.2. The minimum free-stream Reynolds number attained was slightly less than 1,000 per inch.

The assistance of Mr. Graydon A. Elliott in collecting the data is gratefully acknowledged.

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Mr. Fred L. Daum has been an aerospace research engineer with ARL's Fluid Dynamics Facilities Research Laboratory since January 1965. However, he has been with ARL itself (or its predecessor organizations) since 1950. He has been principally concerned with the study of the problems of air condensation in hypersonic wind tunnels, serving as Group Leader of the Gas-dynamics Group.

Mr. Daum was graduated from the University of Cincinnati in 1941 with the degree of Aeronautical Engineer. He subsequently accumulated about 45 graduate credit hours in mathematics and supersonic aerodynamics at the University of Virginia and Ohio State University.

From July 1941 to the present, Mr. Daum has been employed successively by the National Advisory Committee for Aeronautics at Langley Field, Va., by the Air Materiel Command at Wright-Patterson AFB, Ohio, and by ARL or its predecessor organizations.

Mr. Joseph J.S. Shang has been employed at ARL's Hypersonic Research Laboratory since February 1967. He received his B.Sc. in Mechanical Engineering from Cheng-Kung University in Taiwan, and his M.Sc. in Aerospace Engineering from the Polytechnic Institute of Brooklyn in 1962. He has also recently received his Ph.D. in Aerospace Engineering from Ohio State Universiity.

optimal station keeping at the earth-moon libration points

DR. LYNN E. WOLAVER,
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In the restricted three-body problem there are five points of equilibrium such that, if a particle were placed precisely at one of these points, it would maintain its configuration with the two larger bodies (Figure 1). Such points are called the Lagrange libration points. The Earth-Moon-spaceship system forms such a restricted three-body problem. In the real world, however, the sun has a large perturbing effect, and the equilibrium is destroyed. It thus becomes necessary to add a thrust force in order to achieve stability.

A recent thesis completed at the Air Force Institute of Technology under the sponsorship of the Applied Mathematics Research Laboratory, ARL, has developed a control system for maintaining a space vehicle in close proximity to one of the Earth-Moon triangular libration points while minimizing fuel consumption. The problem was formulated as an optimal state regulator problem. A quadratic performance criterion was used which led to a simple linear feedback control system. Given a measurement of the position and velocity state variables, an on-board computer determines the thrust levels required to keep the space vehicle within a prescribed distance. The thrusting program gives a path which is periodic about the libration point. The closer one wishes to keep the vehicle, the more thrust is required.

Figure 2 indicates the thrust required to keep the peak deviation to certain prescribed values. These thrust levels are extremely small. As an example, a 1,000-pound satellite requires an average thrust of about 0.0018 pound

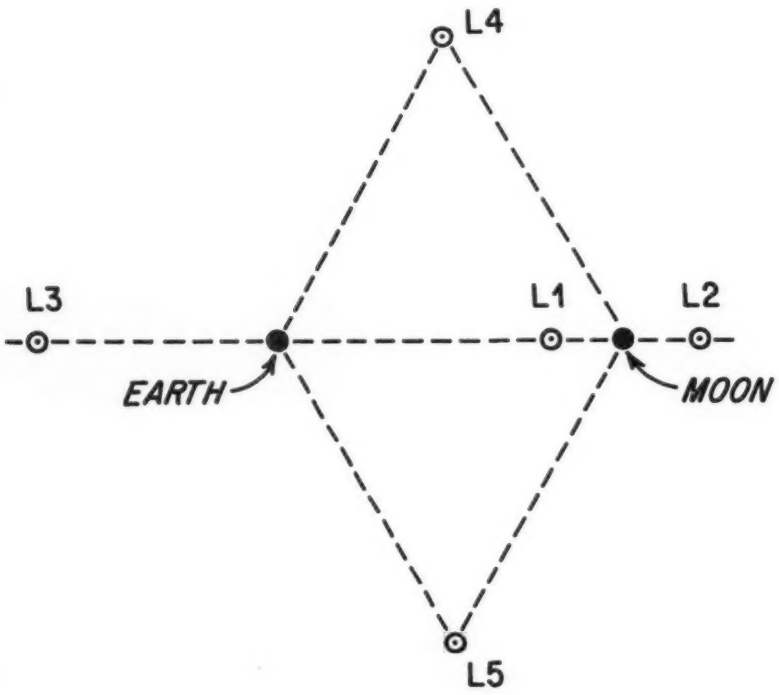

Figure 1. Libration points of the restricted three-body problem.

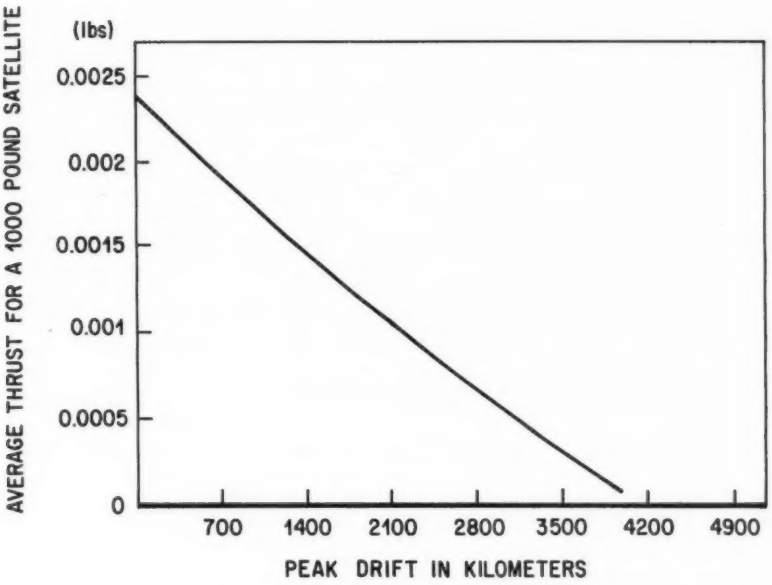

Figure 2. Thrust required to keep the peak drift of a 1,000-lb. satellite to values indicated.

to confine its drift to a 500-mile radius of the libration point. The thrust is continuous and rotates with a period of about 15 days. Captain Isaac R. Steinberg, who carried out the analysis, suggested that only 2 firings a day would adequately approximate the continuous thrust vector with sufficient accuracy. Additional work is being carried out to study the optimal control at the collinear libration points and to study the sensitivity effects of errors in the measurements of the state variables.

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Dr. Lynn E. Wolaver, formerly Deputy Director, became the Director of the Applied Mathematics Research Laboratory, ARL, in June 1967. He is also Professor of Mechanics on the doctoral faculty at the Air Force Institute of Technology, and a lecturer in mathematics at Wright State University. His current research is in the areas of celestial mechanics and in modeling and controlling nonlinear systems.

Dr. Wolaver received his B.S. in 1949 and his M.S. in 1950, both from the University of Illinois. In 1964 he was awarded his Ph.D. in Information and Control Engineering by the University of Michigan. He has been working at Wright-Patterson AFB since 1950 and at ARL since 1956.

Dr. Wolaver is listed in *American Men in Science*, *Who's Who*, *Leaders in American Science*, *Directory of International Biography*, and the *World Space Directory*. He has published more than 40 papers in the fields of navigation, astrodynamics, and nonlinear systems analysis.

NEW GRAVITY TEST POSSIBLE*

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A recent study of two competing gravitational theories indicates that there is a possibility of using existing equipment to determine which one is valid. The competing theories in question are (1) Albert Einstein's general theory of relativity–the gravitational theory that has been almost universally accepted since its proposal in 1916–and (2) a scalar-tensor theory of gravity that has received considerable attention since 1961.

Drs. Jeffrey H. Winicour and David C. Robinson** of the General Physics Research Laboratory, ARL, show that the theories differ in their predictions about the kinds of gravity waves that should be given off during the formation of neutron stars. However, theorists believe they are formed when ordinary stars no longer have enough fuel to keep from collapsing under the force of their own gravity.

Writing in *Physical Review Letters*, (1) a publication of the American Physical Society, Drs. Winicour and Robinson show that gravity-wave detectors recently built by Dr. Joseph Weber of the University of Maryland (two at the University of Maryland and one at the Argonne National Laboratory, Chicago) may be sensitive enough to measure the type of wave generated when a neutron star forms. This may enable physicists to

**Excerpted from an American Institute of Physics news release written by Science writer Bob Holcomb.*

***Dr. Robinson is a National Academy of Sciences Postdoctoral Resident Research Associate.*

determine which theory made the correct prediction.

Because neutron-star formation is relatively rare, and since Dr. Weber's detectors were not designed to distinguish between the kinds of radiation predicted by the two theories, there is only a slim chance that a test can be made in the near future. However, the possibility of experimentally checking gravity theory and neutron-star theory makes even this slim chance seem attractive.

The discovery of pulsars early in 1968 gives added interest to the paper by Winicour and Robinson. Recent evidence indicates that the 25 or so pulsars that have been discovered may be neutron stars. Therefore, any work that increases our understanding of gravity and neutron stars can also increase our understanding of pulsars.

The historical background behind these developments may be traced back to the account of gravitation published by Isaac Newton in 1687, as based upon traditional Euclidean geometry, and a calculus that Newton invented in order to work out his theory. In the middle of the 19th century Georg Friedrich B. Riemann generalized Euclidean geometry, and it was this generalization that Albert Einstein used, along with a tensor calculus, to develop the general theory of relativity.

There are several alternate approaches to gravitational theory, including one that involves the use of a scalar calculus in addition to the tensor calculus. Several relativists, including Einstein, have considered scalar-tensor approaches to gravitation. In 1961, Dr. Carl Brans of Loyola University in New Orleans, and Dr. Robert Dicke of Princeton University proposed a scalar-tensor theory that is now receiving considerable attention.

The observational differences predicted by general relativity and the Brans-Dicke theory are difficult to measure. Since 1961 Dr. Dicke has conducted one experiment that some physicists have interpreted as showing a difference, and several experiments, designed to distinguish between the theories, are now in progress. However, there is no experimental work that unequivocally shows a difference in the two approaches to gravity.

Contained within the equations of general relativity is the prediction that an oscillating object should generate gravitational waves. An analogous situation is the generation of electromagnetic waves by an oscillating charged body.

In electromagnetism, a body with one set of charged poles can produce dipole radiation. Higher orders of radiation (quadropole, octapole, etc.), are possible if more than one pair of charges are present. According to general relativity, only quadropole or higher orders of radiation are possible; but the scalar component of the Brans-Dicke theory allows monopole radiation.

Compared with electromagnetic radiation, gravitational radiation is quite weak, and it is only recently that technical advances have opened up the possibility of detecting it. Dr. Weber's detectors are designed to detect radiation (of the Einstein variety) from reasonable astronomical sources such as rotating stars or collapsing supernovae. Since early 1967, the two gravity-wave detectors that he has at the University of Maryland have measured about one "event" per month. So far there has been no definite way of knowing if these are gravity waves; but it is likely that at least some of Dr. Weber's "events" are the result of gravitational radiation.

In their article, Drs. Winicour and Robinson show that the radiation produced when neutron stars are formed from collapsing supernovae can be detected more easily if the Brans-Dicke theory is correct. That is, the monopole radiation is stronger than the mulitpole radiation predicted by general relativity. Definite proof of monopole radiation, and hence of the Brans-Dicke theory of gravitation, would require a combination of circumstances that is somewhat unlikely at the present time.

The collapse of supernovae to form neutron stars is relatively rare. Only 3 observations of exploding supernovae have been recorded in all history (in the years 1054, 1572, and 1604). It is possible that not all supernovae are observed; but even the most generous estimates of neutron-star formation give a rate of only 1 every 20 years.

The oscillations that produce the gravity waves are damped out in about one hundredth of a second, so the collapsing star must be observed during this time. Catching such a rare event at present is unlikely, but this situation may not continue. Since little is known about neutron stars (or pulsars), there is the possibility that future information will enable astronomers to know when and where to look for the formation of neutron stars by supernovae collapse. It is also possible to build gravity-wave detectors that are more sensitive to the kind of radiation expected from neutron-star formation.

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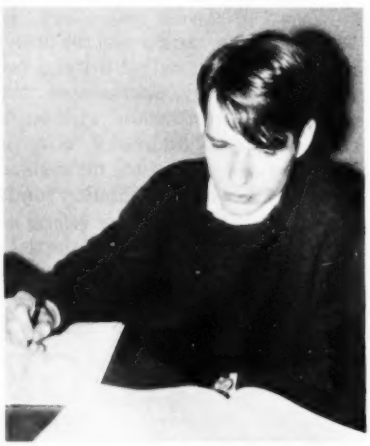

Dr. Jeffrey H. Winicour received a B.S. Degree from the Massachusetts Institute of Technology in 1959 under a Sloan Scholarship, and a Ph.D. degree from Syracuse University in 1964, under an NSF Fellowship. His doctoral research was an investigation of the gravitational coupling of radiation fields in the framework of the general theory of relativity.

After completing his graduate work at Syracuse University, Dr. Winicour spent the summer of 1964 as a post-doctoral fellow at the Brandis Summer Physics Institute. He then came to ARL's General Physics Laboratory as a research physicist in the field of gravitation and general relativity.

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